

CINERADIOGRAPHY IN NORMAL AND ABNORMAL PHARYNGO – ESOPHAGEAL DEGLUTITION

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This thesis is based on the following papers

- I O. Ekberg and G. Nylander
Cineradiography of the pharyngeal stage of deglutition in
150 individuals without dysphagia.
Submitted to Br J Radiol
- II O. Ekberg and G. Nylander
Cineradiography of the pharyngeal stage of deglutition in
250 patients with dysphagia
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- III O. Ekberg and G. Nylander
Pharyngeal constrictor paresis in patients with dysphagia -
A cineradiographic study.
Submitted to Radiology
- IV O. Ekberg and G. Nylander
Dysfunction of the cricopharyngeal muscle - A cineradiogra-
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Submitted to Radiology
- V O. Ekberg and S. V. Sigurjónsson
The movement of the epiglottis during deglutition -
A cineradiographic study
Submitted to Ann Otol Rhinol Laryngol
- VI O. Ekberg
Epiglottic dysfunction during deglutition in patients
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- IX O. Ekberg
Cervical oesophageal webs in patients with dysphagia
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These papers will be referred to in the text by their Roman numerals.

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INTRODUCTION

Deglutition implies the act of swallowing, i.e., transportation of material from the oral cavity to the stomach. The act of deglutition constitutes three stages: the oral, the pharyngeal and the esophageal. The oral stage implies the mincing of food particles by chewing to small pieces and the mixing of these with the saliva. The oral stage also includes the formation of a bolus and the transportation of this bolus through the fauces pharyngis into the pharynx.

The pharyngeal stage of deglutition involves the transportation of the bolus into the esophagus and also the protection of the airways from the passing bolus. The esophageal stage of deglutition implies the further transportation of the bolus to the stomach. The present investigation deals with the pharyngeal stage of deglutition from exclusively a radiologic point of view. Volunteers without dysphagia and dysphagial patients were included in the investigation.

The pharynx is routinely radiographically examined with plain films, films taken after barium swallowing with contrast medium coating of the mucosa, and films taken during barium swallowing. This technique is well established and convenient for disclosing morphologic lesions and possibly also morphodynamic changes like webs and diverticula. (102).

Another radiographic modality that can be used for examination of the pharynx is cineradiography. This technique permits a continuous registration of functional events. The film can be analyzed later with varying film-speed and rapid events can be studied in slow motion for a detailed examination which can be done repeatedly. Therefore cineradiography should be a suitable technique for examination of the pharyngeal stage of deglutition which involves rapid and complex courses of events.

During the early radiologic era observations of the swallowing act were made by fluoroscopy (26). Later observations were also carried out using single-film technique (17, 19, 25, 71). When cineradiography was made available this technique was utilized for analyzing the act of swallowing (11, 12, 42, 53-55). The cineradiographic investigations increased substantially the understanding of the complex mechanism of pharyngeal deglutition (86, 88, 89). However, till now no comprehensive description of the cineradiographic spectrum of normal deglutition has been reported. This means that information has been lacking about the borderline between the normal and pathologic patterns of deglutition. A detailed knowledge about the delineation between normal and pathologic is mandatory for the evaluation of cineradiographic examinations of patients with dysphagia.

Only two studies utilizing radiographic technique for assessing the spectrum of abnormalities among patients with dysphagia have been published. In 1931 and 1935 Macmillan published his results from single film examinations of 1600 dysphagial patients (67, 68). About 30 percent of his patients suffered from a foreign body in the esophagus while about 14 percent had a malignant lesion in the upper third of the gullet, including the pharynx (68). He also described the presence of webs, palsies, fibrosis and spasm of the superior esophageal sphincter among these dysphagial patients. Radiographic studies of cricopharyngeal dysfunction together with an assessment of their frequency among patients referred for radiographic examination have been published (13, 30, 90, 92). Reports concerning the incidence of cervical esophageal webs in dysphagial patients using radiographic technique have been published (27, 28, 36, 68, 71, 79, 91, 96, 99).

However, no report seems to have been published on the types and frequencies of functional abnormalities in the act of swallowing among patients with dysphagia using cineradiographic technique, and therefore such an investigation is warranted.

HISTORICAL REMARKS AND BACKGROUND

Passage of the bolus through the pharynx

Harvey in his classical description on the physiology of the animal body, described deglutition to be carried out "smoothly and regularly" (46). During the 18th century elaborate anatomic dissections were performed by, among others, Boerhave and Hallert (cited by Ramsey et al. 86). Their studies led to detailed information about the morphology of the pharynx and its surrounding structures. They were convinced that all structures in the pharyngeal area were adopted to their defined purpose. One of the fundamentals of Boerhaave and Hallert's description was that the muscles took part in the swallowing act in a specific order beginning proximal in the gullet and traversing it in the distal direction. Magendie, the renowned French physiologist, subdivided the act of swallowing into three stages according to anatomical and functional compartments (69). Magendie ascribed the constrictor pharyngeal musculature to be responsible for the propagation of the bolus through the pharynx. He also claimed that the epiglottis during swallowing tilted down to cover the laryngeal vestibule.

Kronecker and Meltzler studied the act of swallowing in animals with the aid of manometric measurements and conjectured that the bolus was passed from the oral cavity into the pharynx and down the esophagus by a vigorous and rapid contraction of the mylohyoid muscle (61). This suggestion was based on observations that when the mylohyoid muscle was cut in a dog, the animal could no longer swallow fluids. They contradicted Magendie's suggestion about the peristaltic activity in the pharyngeal constrictors. Kronecker and Meltzler claimed that pharyngeal and esophageal constriction did take place but not until the bolus had already passed the pharynx and these contractions were only of secondary importance.

The first radiographic investigation of the swallowing act was published by Cannon and Moser in 1898 (26). They used bismuth subnitrate as a contrast medium in the bolus and measured the

time lapse for the bolus to pass from the mouth to the stomach. Radiography made it possible to study the mechanism of swallowing without surgical intervention, introduction of manometric equipment and anesthesia.

Cannon and Moser found that a liquid bolus passed so rapidly through the gullet that it according to their opinion could not be driven by peristaltic activity but depended instead on the mechanism earlier proposed by Kronecker and Meltzler, i.e., a vigorous and rapid contraction of the mylohyoid muscle. However, observations from swallowing of solid boluses in horse and man were interpreted as relying more on the ability of the pharyngeal and esophageal constrictor peristalsis, while in dog even a solid bolus was thought to be squirted into the esophagus. In this way Cannon and Moser seemed to have confirmed the two partly contradictory suggestions, namely the theory of the mylohyoid muscle contraction as the active part of deglutition and the peristaltic theory relying on the constrictors of the pharynx and esophagus.

In 1930 Barclay reported his observations on deglutition in which he stressed that the bolus was carried from the back of the tongue to the clavicular level of the esophagus by a negative pressure (17). The mechanism producing the negative pressure was claimed to be induced by an elevation of the larynx combined with a backward movement of the tongue, which during the initiation of the swallowing act should obliterate the pharyngeal space completely for a fraction of a second. With the nose, mouth and larynx closed, the reopening of the pharynx was claimed to produce a negative pressure that sucked the bolus down the pharynx. He also reported from observations on himself that it was easier to swallow if the swallowing was preceded by "sucking the teeth". Barclay's theory about a negative pressure in the pharynx was supported by Laurell (62, 63).

Negus performed elaborative dissections of different species of animals and supposed that the bolus, like Barclay had claimed, was passed through the pharynx by the action of a negative

pressure (76). However, later Negus modified his opinion and pharyngeal peristalsis was proposed to have significance due to the consistency of the bolus (77). Fairly modern anatomic textbooks quote Negus' early statements and claim that swallowing is accomplished by a negative pressure in the pharynx and upper esophagus (43).

Fluoroscopy and single-film technique had made it possible to study the act of swallowing, but still more detailed information became available when the cineradiographic technique was introduced (42, 53-55). With this technique it became possible to study such phenomena as the movements of the epiglottis, closure of the laryngeal vestibule and also the presence of peristalsis in the pharyngeal constrictor musculature during swallowing (4-6, 15, 86-89).

The epiglottis during deglutition

Much controversy has concerned the question of whether or not the epiglottis takes an active part in the swallowing act. Magendie claimed that the epiglottis tilted down over the upper laryngeal aperture (69). However, he doubted that the epiglottis acted as a shelter of the vestibule. This statement was based on the results from experiments where the epiglottis was excised in experimental animals without giving rise to any swallowing difficulties.

Kronecker and Meltzler claimed that the epiglottis played an active role during swallowing as a shelter for the laryngeal inlet (61). They also attributed a second function to the epiglottis during deglutition. They claimed that the epiglottis as it tilted down gave the passing bolus an extra push so that it reached into the esophagus. This latter suggested role of the epiglottis has gained little or no acceptance.

Anderson Stuart had the opportunity of observing the epiglottis of a patient through a postoperative pharyngostoma (1, 2). During deglutition the epiglottis was observed to remain in its upright position. From his observation in this severely disabled

patient Anderson Stuart concluded that the epiglottis served no proper function during deglutition in man whatsoever. This statement based on a rather unquestionable observation gained wide acceptance (43).

Three years after the discovery of the x-ray Cannon and Moser used fluoroscopy to observe that the epiglottis in experimental animals as well as in healthy humans tilted down on swallowing (26). This observation was in 1925 confirmed by another radiologist, Mosher (71).

In spite of Cannon and Moser's, as well as Mosher's, fluoroscopic observations, Negus resolutely claimed that the epiglottis was without function during swallowing (74-77). He stressed that the epiglottis was not essential for the closure of the airways during deglutition. He claimed that the epiglottis was a rudimentary and accessory olfactorial organ. He founded his conclusion on the results from dissections on a variety of species.

Negus's theories were supported by Barclay and by Pressman and Kelemen who claimed that the epiglottis remained immobile during deglutition (17, 19, 84). However, other radiologists, as Welin and Johnstone, could finally show that the epiglottis tilted down over the laryngeal inlet (56, 101). Welin was probably the first one to report on functional abnormalities in the movement of the epiglottis during deglutition (101).

With the introduction of cineradiography it became easier to disclose details in the function of the pharynx during swallowing. The movement of the epiglottis during swallowing was studied and described to take place in a three-step fashion. The first step was described to be from an upright resting position to a transversal position with the tip of the epiglottis against the posterior pharyngeal wall. The second movement was the tilting from the transversal to a vertical position with the tip of the epiglottis reaching down into the inlet of the esophagus. The third movement tilted the epiglottis back to its upright resting position (4-6, 8, 15, 86-89).

An attractive and ingenious theory to explain the second movement of the epiglottis has been proposed by Fink (38-41). According to this theory the epiglottis is folded down over the laryngeal inlet by a lateral compression combined with a cranial traction in the hyoepiglottic ligament.

Closure of the airways during deglutition

The pharynx is the common channel for bolus material and air before each is diverted in its proper direction, i.e., the esophagus and the trachea. This necessitates an effective mechanism by which bolus and probably also air is hindered to escape into the wrong direction. In addition to the larynx the epiglottis is also active in this context. In some species the epiglottis is provided with long lateral folds which meet posteriorly (75). They surround the superior laryngeal inlet on all sides and shut off the air tract with great efficiency. This means that the bolus passes on both sides of the larynx in the so called lateral food channels. In man the lateral food channels are shallow and consist of the piriform sinuses, but they seem to be of minor importance compared to those in other species in which they are deep. In man at least solid and semisolid boluses usually pass in the center of the food channel over the tip of the epiglottis.

As mentioned earlier the superior laryngeal aperture could be inspected by Anderson Stuart in a patient with a large pharyngostoma (1). The epiglottis in this patient did not tilt down over the laryngeal inlet which thereby was left free for inspection. He could register that the inlet was closed and ascribed it to be due to apposition of the two arytenoids and by an apposition of the arytenoids to the fat cushion of the epiglottis, i.e., the fat pad which makes up the fixed part of the epiglottis. He called the lateral thyroarytenoid muscle the sphincter of the vestibule. He denied that the laryngeal vestibule and the rima glottidis was closed during deglutition.

Mosher observed by fluoroscopy that the vestibule seemed to be compressed by apposition of the arytenoids and the fat cushion

of the epiglottis (71).Negus suggested the presence of a superior laryngeal sphincter made up by the paired lateral cricoarytenoid and thyroarytenoid muscles and the interarytenoid muscle (77).

Barclay could observe by fluoroscopy that the vestibule was closed from the superior inlet to the level of the false cords not by constrictors but by compression achieved by the back of the tongue against the elevated larynx (17,19).

Johnstone supported the view of compression of the vestibule by the base of the epiglottis against the arytenoids (56). However, he claimed that the rima glottidis did not close during swallowing.

Based on a cineradiographic study Rushmer claimed that the vestibule was not closed although the rima glottidis had closed (88). He suggested that a "vapor lock" over the vocal cords hindered the bolus to pass into the vestibule.

Ardran and Kemp have described the closure of the larynx to be accomplished by five defined stages (4-6, 8, 9). The first is the narrowing of the vestibule due to apposition of both the vocal and the false cords and also by a forward movement of the arytenoids. The second stage is the tilting down of the leaf of the epiglottis, its tip resting against the posterior wall of the pharynx. The third stage of the closure is a further forward tilting of the arytenoids. The fourth one is a backward bulging of the lower part of the epiglottis into the vestibular lumen which was claimed to result in further bulging of the vestibular folds and obliteration of the laryngeal ventricles. The fifth stage is the sealing of the laryngeal aperture by the epiglottis. One of the fundamental principles of Ardran and Kemp and also of Fink is the closure of the laryngeal vestibule was solely dependent on extrinsic muscles. They exclude the presence of a constrictor of the superior laryngeal aperture (5, 40).

With the aid of cineradiographic investigations Ramsey could observe that there was a clear peristaltic activity that closed

the vestibule from the vocal folds to the superior laryngeal aperture (86). In this way particles that regularly passed into the laryngeal vestibule and even to the level of the vocal folds were expelled and did not reach the trachea.

ANATOMIC CONSIDERATIONS

General considerations

The pharynx connects the nasal and oral cavities with the larynx and esophagus. The nasal cavity opens into the cranial and anterior part of the pharynx. The oral cavity has connection with the pharynx via the fauces pharyngis in the anterior and middle part of the pharynx. The larynx is via the laryngeal vestibule connected to the anterior wall of the lower part of the pharynx. The transition between the pharynx and the esophagus is about at the level of the sixth cervical vertebra.

Pharyngeal constrictor musculature

The constrictor musculature of the pharynx is composed of three portions, i.e., the superior, middle and inferior. The superior portion of the constrictor is attached to the base of the skull, the pterygomandibular raphe, the mandible and the tongue. The middle constrictor emerges from the hyoid bone and the stylohyoid ligament. The inferior constrictor emerges from the thyroid and cricoid cartilages. The muscles from each side unite posteriorly into the pharyngeal raphe. The muscles function as one unit and a contraction brings about a propulsive peristalsis that normally passes through the pharynx without interruption.

The epiglottis

The cartilage of the epiglottis has the form of a racket, where the petiolus corresponds to the handle. The petiolus is attached by the thyroepiglottic ligament to the posterior and medial aspects of the thyroid cartilage. The anterior aspect of the epiglottis is connected by the hyoepiglottic ligament to the hyoid bone. The epiglottis is laterally fixed on both sides by the pharyngo-epiglottic plicae. Three muscles insert on the

epiglottis: the stylopharyngeal, the aryepiglottic and the thyroepiglottic muscle. The stylopharyngeal muscle emerges from the styloid processus. The muscle passes in an anterior-inferior direction from the processus and passes between the superior and middle pharyngeal constrictor to the lateral margins of the epiglottis and the thyroid cartilage. The fan-shaped muscle also merges with the palatopharyngeal muscle. The aryepiglottic muscle passes beneath the aryepiglottic fold from the aryregion to the lateral border of the epiglottis. The thyroepiglottic muscle emerges from the internal surface of the thyroid cartilage and runs in a superior and posterior direction. The muscle is attached to the lateral border of the epiglottis and the aryepiglottic fold.

The laryngeal vestibule

The laryngeal vestibule constitutes the air-filled cavity between the vocal folds and the pharynx (VII, Fig. 1). Its cranial border is made up of the free margin of the epiglottis, the aryepiglottic folds and the arytenoid region. The anterior wall and the roof of the vestibule are composed of the posterior aspect of the epiglottis, its movable as well as its fixed portion and a fat cushion covering the thyroid cartilage down to the level of the anterior laryngeal commissure. The side walls are composed of the thyroid cartilage and its overlying structures, i.e., the thyroepiglottic and thyroarytenoid muscles on both sides as well as the quadrangular membrane. The inferior part of the thyroarytenoid muscle is composed of a medial segment - the vocal muscle - and a lateral segment. The superior part constitutes the ventricular muscle. Between these two muscles - the vocal and the ventricular - there is a bilateral recess formation known as the laryngeal ventricles or the sinuses of Morgagni. The thyroepiglottic muscles form a continuation in cranial direction of the thyroarytenoid muscles but are situated more laterally. The laryngeal ventricles constitute the caudal border of the lateral walls of the vestibule.

The vestibule can be described as a bent tube with about a 45 degree angulation. This angulation divides the vestibule anatom-

ically into a cranial and a caudal segment (VII, Fig. 2). The cranial segment, subsequently denoted the *subepiglottic space*, is separated from the caudal segment, subsequently denoted the *supraglottic space*, by an imaginary plane between the interarytenoid incisure and the incisure of the thyroid cartilage. This subdivision of the vestibule corresponds roughly to the position of the adjacent muscles, especially the thyroarytenoid muscles lateral to the supraglottic space and the thyroepiglottic muscles lateral to the subepiglottic space.

The cricopharyngeal muscle

The cricopharyngeal muscle, is composed of three portions (IV, Fig. 6). The superior portion of the muscle is called *pars obliqua* and runs its course in close connection with the inferior pharyngeal constrictor. Its muscle bundles emerge from the lateral aspects of the cricoid cartilage and project in an oblique craniodorsal direction to join the muscle of the contralateral side in the raphe pharyngeus of the posterior wall of the pharynx. The middle portion of the cricopharyngeal muscle is attached to the posterior and lateral aspects of the cricoid cartilage from which it surrounds the esophagus in a semicircular way. It is separated from the *pars obliqua* by a triangular area of fibrous tissue. This triangular area has been called Killian's dehiscence, and is characterized by its scarcity of musculature. The inferior portion of the cricopharyngeal muscle, *pars longitudinalis*, is attached to the inferior aspect of the cricoid cartilage. The muscle bundles emerge downward and converge with the longitudinal muscle bundles of the esophagus. Their function seems to be to elevate the esophagus during deglutition. Subsequently the term 'cricopharyngeal muscle' is used to designate the transversal portion of the muscle.

Neuroanatomic and neurophysiologic consideration

From receptors in the mouth, pharynx and larynx afferent neurons pass in the fifth, ninth and tenth cranial nerves. After entering the medulla these fibers reach the tractus solitarius in the floor of the fourth ventricle dorsal to the nucleus ambiguus.

These central processes of the afferent neurons have synapses in the nucleus of the tractus solitarius, here all the associational neurons related to the ninth and tenth cranial nerves are located. Some axons pass from this nucleus to the dorsal motor nucleus of the vagus, which is the origin of the parasympathetic portion of the vagus nerve supplying the viscera from the middle of the esophagus and in anal direction. The majority of the associational neurons from the nucleus solitarius have synapses in various centers in the reticular formation of the medulla, one of which has been termed the swallowing center. From cells in the swallowing center secondary associational neurons may pass to the dorsal motor nucleus of the vagus nerve and the nucleus ambiguus. The nucleus ambiguus is the somatic motor nucleus of the ninth, tenth and eleventh cranial nerves. The nucleus is located in the lateral aspect of the medulla oblongata in the floor of the fourth ventricle. It has a considerable extension in the longitudinal direction of the medulla.

The cortical motor center of the larynx and pharynx is situated in the lowest part of the precentral convolution. The axons of the cortical cells pass, as the corona radiata, the internal capsule and the cerebral peduncle to the nucleus ambiguus mainly on the contralateral side but also to the ipsilateral nucleus (35).

The axons of the ninth, tenth and eleventh cranial nerves have been shown to originate at different loci within the nucleus ambiguus (16). The glossopharyngeal nerve derives its axons from the rostral end of the nucleus ambiguus, the cervical vagus from its rostral and intermediate portions while the accessory nerve derives its axons from the caudal portion of the nucleus. There does not seem to be any strict borderline between the nuclei of the ninth, tenth and eleventh cranial nerves. Furthermore, the fibers from these nerves merge to form the so-called pharyngeal plexus encircling the constrictor musculatures of the pharynx. The motor nerve supply of the cricopharyngeal muscle is also derived from the cervical sympathetic via the uppermost cervical ganglion.

The activity of the pharyngeal constrictors can be initiated as other striated muscles by efferent impulses from the cortex. It can also be initiated by afferent impulses from the pharynx and a reflex mechanism via the swallowing center in the medulla. Once the pharyngeal muscle activity has been initiated it seems impossible to interrupt the activity at least not without consequences like passing of bolus material to the laryngeal vestibule and so on.

The cricopharyngeal muscle is between swallowings kept in constant tonic contraction. This is mediated by a sympathetic stimulation while relaxation of the muscle is effected by parasympathetic stimulation (57, 94). According to Kirchner and Sjöberg a relaxation of the cricopharyngeus would imply a cessation of sympathetic stimulation followed by a vagus-mediated relaxation (57, 94). The cricopharyngeal muscle begins to relax at the same moment as the pharyngeal constrictors start to contract, i.e., when the bolus enters the fauces pharyngis and before the bolus has reached the pharyngeal outlet at the level of cricopharyngeal muscle (14, 52).

This suggests that pharyngeal contraction and cricopharyngeal relaxation are initiated by one and the same trigger mechanism - a sensory pharyngeal stimulation.

PURPOSE OF THE PRESENT INVESTIGATION

The aim of the present investigation was to evaluate the cine-radiographic pattern of pharyngeal deglutition among nondysphagial individuals and to give a comprehensive description of aberrations from normal deglutition in patients with dysphagia. Thus, the purpose was:

- to perform a cineradiographic study of the pharyngeal stage of deglutition in a group of volunteers without dysphagia in order to delineate the range of radiographic patterns of normal deglutition (I).
- to describe different functional disorders in the swallowing act among patients with dysphagia referred for radiographic examination, using a cineradiographic technique (II).

- to describe the cineradiographic pattern of circumscribed paresis of the pharyngeal constrictor musculature among patients with dysphagia (III).
- to study how often and to what extent a disturbed relaxation of the cricopharyngeal muscle appeared in patients with dysphagia on routine radiographic examinations and on cineradiography (IV).
- to study the movements of the epiglottis with the aid of cineradiography in an attempt to elucidate the mechanism behind its tilting down during normal swallowing (V).
- to analyze the motion pattern of the epiglottis in dysphagial patients during swallowing and to disclose the pathophysiologic significance of the epiglottic dysmotility (VI).
- to study the closure of the laryngeal vestibule with cineradiography during normal swallowing (VII).
- to study a group of dysphagial patients with defective closure of the laryngeal vestibule during swallowing in order to elucidate details in the pathophysiology in the closure of the vestibule among these patients (VIII).
- to study the presence and appearance of cervical esophageal webs among patients with dysphagia on routine radiologic examinations and on cineradiography (IX).

MATERIAL

Nondysphagial volunteers

Patients referred to the Radiological Department for examinations of other organs than pharynx and esophagus were asked to participate in this study. The type of radiographic examinations among the patients varied as seen in Table 1. Seven nondysphagial staff members were also included. The volunteers were interviewed and asked particularly about any earlier or present dysphagia. All patients with the slightest suspicion of swallowing difficulties were excluded from the study. There was a total of 150 individuals (79 men and 71 women with a mean age of 52 years, range 20-82).

Type of examination	Number of patients
Barium examination of stomach and duodenum	69
Peroral cholecystography	50
Positive contrast herniography	12
Barium examination of small bowel	7
IVP	3
Skeletal examination	2

Table 1 Type of examination among 143 nondysphagial volunteers.

Dysphagial patients

Patients with dysphagia who were referred for radiographic pharyngo-esophageal examinations during a two-year period were included. There were 103 men and 147 women with an age between 18 and 95 years (mean 61 years). The material consisted of 250 consecutively performed cineradiograms of the pharyngo-esophageal act of swallowing.

METHODS

The volunteers were examined with cineradiography only, while the patients were also examined with conventional single film technique. This included plain films and films taken during and after barium swallowing. The plain films and the films during barium swallowing were obtained in the PA and left lateral projections. The films after barium swallowing were taken in lateral PA, LAO and RAO projections.

The cineradiograms were obtained with the aid of a high-speed camera (Camématic GV Super from Brevets Countant-Mathot) which was mounted on a 9"/5" x-ray intensifier (Cesiumiodine, Philips XG 2010/20). The exposures were made with the aid of a cine-pulse unit (Philips XG 7002). The distance between the x-ray tube and the input screen was 115 cm. The exposures were made at between 70 and 80 kV with a pulse time of 1, 3 or 5 msec and with a maximum tube current of 130 mA. The cineradiograms were obtained at a speed of 50-100 frames per second. Gevapan 36

negative films were used.

The patients were asked to swallow a large mouthful of contrast medium followed by several secondary swallowings. The contrast medium used was Parytgen^R (60 % w/w). The swallowed amount of contrast medium will subsequently be designated, somewhat inaccurately, as the bolus.

The cinefilms were analyzed on a Steenbeck Analector (ST 1100 W) permitting display at varying speeds including a frame by frame analysis.

The cineradiograms were scrutinized concerning the following morphodynamic and functional details of deglutition:

- ability of the palatopharyngeal sphincter (Passavant's ridge) and the soft palate.
- ability of the pharyngeal constrictor musculature seen as a defect, absent or interrupted peristalsis preferably in the posterior wall.
- movements of the epiglottis during deglutition.
- closure of the laryngeal vestibule.
- cricopharyngeal muscle dysfunction defined as an indentation in the posterior wall of the pharyngoesophageal junction at the moment when the cervical portion of the esophagus down to the level of the seventh cervical vertebral body was distended by the bolus as seen in the lateral projection. The depth of the indentation was arbitrarily used to classify the indentations into three degrees: 1) indentations less than one fourth, 2) less than half and 3) more than half of the diameter of the adjacent esophagus.
- the further behavior of the cricopharyngeal indentation during the passage of the bolus was also studied, i.e., whether it remained unchanged (continuous type) or disappeared (transient type) during the passage of the bolus (IV).
- presence of webs (IX).
- presence of other lesions like pouches, significant tumors and so on (II).

SUMMARY OF RESULTS

Regular pattern of deglutition

In 124 volunteers (83 %) the cineradiographies disclosed the swallowing to occur in a sequential, coordinated and rapid manner (I, Fig. 1). The swallowing act could be divided principally into different steps and followed a certain course of events (I).

The bolus was passed from the oral cavity into the pharynx through the fauces pharyngis by a backwards sweeping movement of the tongue. The epipharynx was shut off from the mesopharynx by an apposition of the soft palate to the posterior wall of the pharynx. The soft palate formed a cranioconvex vault while the posterior pharyngeal wall was seen to bulge forwards (Passavant's ridge). At this moment the rima glottidis was closed.

The hyoid bone was lifted in a posterior and superior direction and later somewhat anteriorly. Simultaneously with the elevation of the hyoid bone the supraglottic space was closed by an apposition of its lateral walls. The elevation included also the larynx and pharynx. During this movement the thyroid cartilage approached the hyoid bone and the epiglottis tilted down to a transversal position. The pharyngeal constrictor musculature started to contract and the bolus was propelled down the pharynx by a peristaltic stripping wave.

The movable part of the epiglottis was then tilted down over the arytenoids. The movements of the epiglottis during deglutition has been dealt with in paper V. By this maneuver the subepiglottic space was compressed in a superior-inferior direction by the apposition between the fat cushion of the fixed part of the epiglottis and the arytenoids. The closure of the vestibule is dealt with in paper VII.

When the cervical esophagus was well dilated and filled by the bolus no indentation or narrowing of the pharyngoesophageal junction was observed. The peristaltic wave passed the crico-pharyngeal region uninterrupted. When the peristalsis had passed,

the cricopharyngeal muscle remained contracted as an upper esophageal sphincter while the gullet superior and inferior to the cricopharyngeal region relaxed.

At the end of the swallowing act the larynx/pharynx descended and the epiglottis tilted back into its resting upright position. The tongue was moved forwards.

Aberrant pattern of deglutition

Aberrations were found among 26 of 150 volunteers (17 %) and among 200 of 250 dysphagial patients (80 %). A brief summary of these results is given in Table 2. This has been dealt with in papers I and II.

Table 2 Cineradiographic findings among 150 nondysphagial volunteers and 250 dysphagial patients

Type of abnormalities	Volunteers	Patients	p-value *
Paresis of the pharyngeal constrictors	0	25 (10%)	< 0.001
Contrast medium entering the laryngeal vestibule			
Into subepiglottic space	8 (5.3%)	58 (23%)	< 0.001
Into subepiglottic and supraglottic space	0	41 (16%)	< 0.001
Aspiration to trachea from the pharynx	0	4 (1.6%)	< 0.1
Epiglottic dysfunction			
Obliquity during full bolus swallowing	6 (4.0%)	11 (4.4%)	0.84
Absence of 2nd movement	7 (4.7%)	53 (21%)	< 0.001
Immobility	0	19 (7.6%)	< 0.001
Cricopharyngeal dysfunction	6 (4.0%)	55 (22%)	< 0.001
Cricopharyngeal chaliasia	0	1 (0.4%)	
Cervical esophageal webs	1 (0.7%)	38 (15%)	< 0.001
Zenker diverticulum	0	5 (2.0%)	0.1

* p-value for the observed difference between the volunteers and the patients.

Pharyngeal constrictor paresis is dealt with in paper III. No volunteer was found to have paresis of the pharyngeal constrictor musculature. Pharyngeal constrictor paresis was observed in 25 patients with dysphagia. The observed pharyngeal constrictor paresis among the patients varied in extension. In 6 patients the paresis included the whole musculature, i.e., the superior, middle and inferior portions (III, Fig. 1). In the remaining 19 patients the paresis was confined to a circumscribed portion of the musculature. In 1 patient there was a circumscribed paresis of the superior portion, in 16 there was paresis of the middle portion (III, Fig. 2), while in 2 the paresis included the middle and inferior portions.

Defective closure of the laryngeal vestibule is dealt with in paper VIII. A defective closure of the laryngeal vestibule was observed in 103 of the patients (VIII, Fig. 1). The defect varied in degree from one patient to the other (Table 3). In 58 patients the subepiglottic space did not close properly (VIII, Fig. 2). Consequently, on swallowing the vestibule was filled with contrast medium down to the superior border of the supraglottic space.

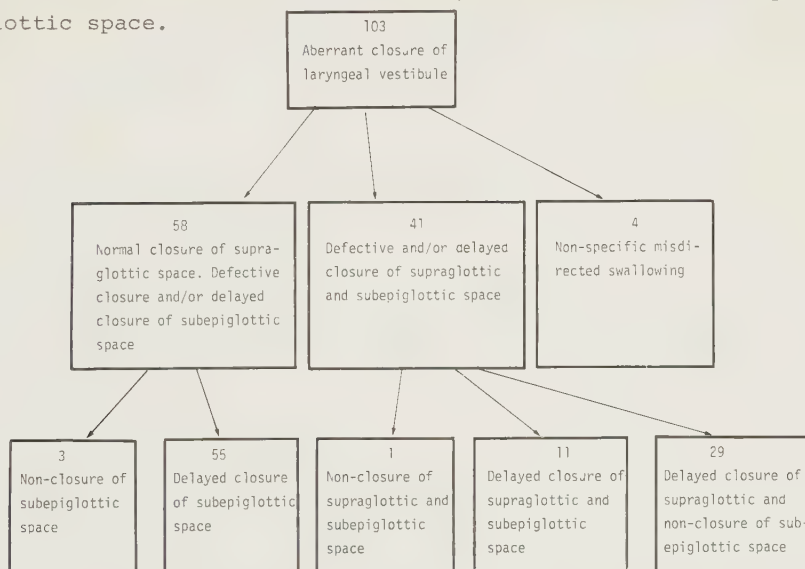


Fig. 1. Distribution of 103 patients with a defective closure of the vestibule according to the cineradiographic findings.

In 41 patients neither the subepiglottic nor the supraglottic space closed properly during the act of swallowing (VIII, Fig. 3). Consequently, contrast medium entered into the vestibule down to the level of the rima glottidis.

In addition a defective closure of the vestibule was encountered in 4 patients as contrast medium entered the vestibule - but not the trachea. However, the cineradiograms gave no information about the mechanisms involved in the misdirected swallowing of these patients.

Dysfunction of the epiglottis is dealt with in paper VI. Dysfunction of the epiglottis was registered in 13 of the volunteers (8 %). In 6 of these the epiglottis attained an obliquity of 30 - 90 degrees seen in the AP projection (I, Fig. 2). In 7 volunteers the second movement of the epiglottis was missing (I, Fig. 3).

Among the dysphagial patients 83 (33 %) displayed functional abnormalities in the movement of the epiglottis. A totally immobile epiglottis during deglutition was seen in 19 patients (VI, Fig. 1). A severely impaired or absent second movement of the epiglottis with its first movement intact was registered in 53 patients (VI, Fig. 2). In 11 patients the epiglottis attained an obliquity in the AP views (VI, Fig. 3).

Dysfunction of the cricopharyngeal muscle is dealt with in paper IV. Cricopharyngeal dysfunction was registered among 6 of the volunteers (I, Fig. 4). In 2 of these the indentation was transient, i.e., it was seen during the early phase of swallowing but disappeared during the late phase. In 4 it was continuous, i.e., remained visible throughout the act of swallowing. In 4 it was of the third degree.

Fifty-five of the patients with dysphagia showed a cricopharyngeal dysfunction. The cricopharyngeal indentation was transient in 36. In the remaining 19 patients the indentation was continuously sustained during the whole act of swallowing. A first degree cricopharyngeal indentation was observed in 29

patients, a second degree in 18 patients and a third degree in 8 patients (IV, Fig. 2).

Of the 29 indentations of the first degree 21 were of the transient type and 8 of the continuous type. The corresponding figures for indentations of the second degree were 15 (IV, Fig. 4) and 3 (IV, Fig. 3), respectively, while all the cricopharyngeal indentations of the third degree were of the continuous type. With conventional examination it was possible to diagnose the cricopharyngeal indentation in 22 of the 55 patients (40 %). (IV, Table I).

One of the patients had an absence of the sphincteric function of the cricopharyngeal muscle (chaliasia). In this patient the peristalsis traversed the pharyngoesophageal junction uninterrupted. However, the superior esophageal sphincter did not remain closed when the bolus had passed but opened simultaneously with the relaxation of the adjacent gullet (II).

Esophageal webs are dealt with in paper IX. A cervical esophageal web was registered in a 72 year old female among the volunteers. Webs were found among 38 of the dysphagial patients. Of these 30 were females and 8 men. This corresponds to 20 percent of the females and 8 percent of the males. In 26 of these the web was demonstrated also on the conventional single-film examinations (68 %). In the remaining 32 percent of the patients the conventional technique failed.

The appearance of webs in the cineradiograms changed during the act of swallowing. In 23 patients the webs were recognized as soon as the contrast medium reached the cervical esophagus, whereafter they remained visible until the peristalsis emptied the esophagus.

In the remaining 15 patients the webs appeared at first when the cervical esophagus had been well filled with contrast medium for a while, i.e., they were formed during the course of the swallowing (IX, Fig. 4).

In 5 of the patients concomitant malignant lesions in the pharynx, larynx, esophagus or stomach were registered.

Zenker diverticula were not registered among the volunteers. In 5 of the patients this type of diverticulum was registered (II, Fig. 6).

Concomitant abnormalities

Concomitant abnormalities was observed among 2 of the volunteers in whom a defective tilting down of the epiglottis was seen together with contrast medium entrance into the vestibule. Concomitant functional abnormalities were observed among 52 percent of the dysphagial patients. The frequency of these concomitant abnormalities according to type is given in Table 4.

	Paresis of pharyngeal constrictors n = 25	Misdirected swallowing n = 103	Epiglottic dysfunc- tion n = 83	Cricophar- yngeal dys- function* n = 55	Webs n=38	Zenker diverticula n = 5
Paresis of pharyngeal constrictors n = 25	0 [*]	23	25	8	3	0
Misdirected swallowing and aspir- ation 23 n = 103	23	24 ^K	65	23	15	2
Epiglottic dysfunction n = 83	25	65	12 ^X	17	8	1
Cricophar- yngeal dys- function* n = 55	8	23	17	20 ^X	18	1
Webs n = 38	3	15	8	18	13 ^X	1
Zenker diverticula n = 5	0	2	1	1	1	2 ^X

* one patient with chhalasia is not included

^X Patients with an isolated abnormality of the type indicated in the headings
n=71 (28%)

Table 4 Functional abnormalities in the act of swallowing according to the presence or absence of concomitant abnormalities.

GENERAL DISCUSSION

The present investigation of nondysphagial volunteers was initiated by an urgent need for a distinct delineation between normal and abnormal radiographic pattern of swallowing. The study was undertaken in order to obtain a control material to be used as a reference in the evaluation of cineradiograms of patients with dysphagia. By comparing the cineradiograms of dysphagial patients with those of the volunteers without dysphagia it would be possible to define the pathologic significance of even small circumscribed isolated aberrations in the swallowing act. As the investigation of the volunteers revealed a symmetric and regular pattern of deglutition in 83 percent of the cineradiograms, this confirmed the assumption that the act of swallowing is accomplished within certain limits. However, it was also obvious that in 17 percent of the volunteers without dysphagia the cineradiograms revealed aberrations from this pattern. These aberrations may be accidental. However, the aberrations appeared unchanged on repeated swallowings and this observation indicates that they were not of an accidental type. A probable explanation to the presence of these aberrations may be the presence of minor lesions in the peripheral nerves or in the muscles. At the first appearance of such circumscribed and isolated dysfunctions a very slight and transient dysphagia may have been felt by the patient. However, small aberrations in the act of swallowing may easily be compensated by the patients. It is well known that even rather extensive dysfunctions have been reported to cease spontaneously or with training (10).

Although the results of the present study confirm previous observations about a symmetric and regular pattern in the swallowing act, the different events during this act could occur with somewhat varied timing (I). This is valid but only to a certain limit beyond which the act of swallowing alters more profoundly. For instance, a delayed closure of the subepiglottic portion of the vestibule will lead to bolus entrance. In the same way a late relaxation of the cricopharyngeal muscle will appear as an indentation in the posterior wall of the uppermost esophagus. A considerable variation in the time for the epi-

glottis to fulfill its movements was also found, but also in the time for the apex of the bolus to transverse from the pharyngeal fauces to the level of the cricopharyngeal muscle. It may well be that every person has a specific pattern of deglutition which by small but definite variations can be distinguished from that of other individuals.

Among the patients with dysphagia an abnormal cineradiographic examination was revealed in 80 percent. The vast majority of these abnormalities were functional and only few morphologic lesions were revealed as for instance 5 Zenker-type diverticula. No patient was found to have an earlier unknown morphologic lesion in the pharynx or in the cervical portion of the esophagus that not had been demonstrated by the preceding conventional x-ray examination. This observation is contradictory to a report of Macmillan in which 14 percent of the patients with dysphagia suffered from malignant lesions (67, 68). The only possible explanation is that the selection of patients has been completely different in Macmillan's investigation and in the present study.

The diagnostic value of cineradiography in the examination of patients with *pharyngeal paresis* was first stressed by Ardran and Kemp who proposed that every patient with unexplained swallowing complaints should be subjected to a cineradiographic examination of pharyngeal deglutition even if the patient's routine pharyngeal examination appeared quite normal (7). They have described absence of motility or weakness of the pharyngeal constrictors in 2 patients as due to partial paresis after poliomyelitis and to a trauma to the neck (7, 10). Only two other reports of circumscribed pharyngeal paresis have appeared in the literature (3, 66). The importance of radiology in the examination of these patients has been confirmed by several authors (10, 22, 23, 29, 34, 50, 64, 72, 80, 81). The pathologic significance of circumscribed pharyngeal paresis has, however, been disputed in clinical materials as well as in experimental investigations (23, 26). On the contrary, total pharyngeal palsy is a well known condition often met with in severely disabled patients (72, 73, 93, 103). The results of the present investi-

gation show that circumscribed pharyngeal paresis of the constrictor musculature is a fairly common phenomenon encountered in about 8 per cent of patients referred for radiographic examination of the pharynx due to dysphagia.

Due to the described arrangement of the nerve supply with a substantial "overlapping" of the nerves within the pharyngeal plexus a total paresis is very rarely, if ever, caused by a vascular lesion. A total pharyngeal palsy is as a rule the result of a widespread lesion involving the whole extension of the nucleus ambiguus or of a myogenic disease. Consequently total pharyngeal palsy is a rare entity that is met with only in severely disabling conditions, such as bulbar poliomyelitis, syringobulbia, amyotrophic lateral sclerosis, disseminated sclerosis and myasthenia gravis (72, 73, 93, 104).

In the early radiologic era the diagnosis of pharyngeal constrictor paresis was based mainly on indirect signs like retention of contrast medium in the gullet. It is true that the examiner can obtain valuable information about the functional state of the pharynx by a skilled fluoroscopy of the pharyngeal stage of deglutition. However, even in experienced hands the examination is time-consuming and difficult as only a minor detail in the act of swallowing can be scrutinized for every swallowing. This means that the patients have to swallow large amounts of contrast medium. This is a minor problem in healthy individuals. However, in disabled patients, especially those with misdirected swallowing, the procedure can be unfeasible (36). The examination may even be hazardous if barium suspension enters the airways. Under normal conditions the act of swallowing includes a sequence of fairly rapid events. The apex of the bolus passes from the pharyngeal fauces to the cervical esophagus in about one third of a second (I). This makes fluoroscopy difficult, especially in patients with malfunctions in the act of swallowing. These patients have a tendency to compensate for their inability by turning the head and moving the trunk in order to involve secondary and accessory swallowing muscles. For this reason smaller aberrations like a circumscribed pharyngeal

constrictor paresis is almost impossible to diagnose with any degree of certainty by fluoroscopy and single-film exposures. With the use of cineradiography the radiologic diagnosis is enhanced and much of the above described inconvenience can be overcome.

The present investigation of nondysphagial volunteers revealed *the tilting down of the epiglottis* to be achieved in a clear-cut two-step fashion. The first movement is from the upright resting position of the epiglottis to a transversal position. This movement can be explained as consequential to the elevation of the hyoid bone and the approximation between the thyroid cartilage and the hyoid bone (V, Fig. 1). This movement of the epiglottis is thereby the result of contraction of the muscles that elevates the hyoid bone, namely: m. stylohyoideus, m. digastricus, m. mylohyoideus and m. geniohyoideus. In addition the thyrohyoid muscle approximates the hyoid bone and the thyroid cartilage. The epiglottis is laterally fixed by the pharyngo-epiglottic plicae and is at the laryngeal elevation and the thyroid approximation to the hyoid bone tilted to the transversal position with these plicae as turning points. The second movement of the epiglottis has been attributed either to the passing bolus which should push the movable lip of the epiglottis further down into the esophageal inlet (5, 15, 88), or to the peristaltic contraction in the pharyngeal constrictor musculature (74). The present investigation has shown that neither of these theories seems to offer a satisfactory explanation of the second epiglottic movement in swallowing (Paper V). The first one is inconsistent since the epiglottis is tilted down into the esophageal inlet

even on a secondary swallowing without any bolus. The second theory is contradicted by the observation that the epiglottis in about half of the volunteers tilted down before it was reached by the pharyngeal peristalsis. Therefore, it is more probable that the second movement of the epiglottis is accomplished by one of the muscles that insert on the epiglottis. These muscles are the stylopharyngeal, thyroepiglottic and aryepiglottic (V, Fig. 4). None of these muscles has such a direction that it is able to tilt down the epiglottis from its upright resting position. However, when the epiglottis has attained a transversal position the conditions may have changed. Still the stylopharyngeal muscle can not possibly bring about the second movement, but it is more likely that a contraction in this muscle results in a tilting back of the epiglottis to the upright position. It is possible that the aryepiglottic muscle may be able to pull the epiglottis downwards against the ary region but never as far down as into the esophageal inlet. When these two muscles have been excluded the thyroepiglottic muscle remains as an able candidate to accomplish the tilting down of the epiglottis. With the epiglottis in the transversal position this muscle has a favorable direction in relation to the epiglottis (V, Fig. 5). A contraction of the thyroepiglottic muscle is therefore very likely to pull the epiglottis down over the ary region. Furthermore, it will change the form of the epiglottis from a downward convex to an upward convex one. A contraction of the aryepiglottic muscle will in this new position of the epiglottis with its tip in the esophageal inlet tighten the laryngeal inlet in the same manner as the string in a tobacco pouch (V, Fig. 5).

The first report on *abnormalities in the movements of the epiglottis* during deglutition seems to have been published by Welin who observed 5 patients with an irregular and jerky tilting back of the epiglottis to its upright position (101). Obliquity of the epiglottis during deglutition in patients with neuromuscular disorders has also been reported (10, 58, 93). No other reports have been found about epiglottic dysfunction during swallowing. In an earlier report of Silbiger et al. it was claimed that aberration from a symmetric pattern of movement, including obliquity, is not seen in normal individuals (93).

The present investigation has shown that in volunteers without dysphagia aberration from the symmetric tilting down of the epiglottis exists. Obliquity of the epiglottis was registered among 4 percent of the patients with dysphagia which is the same frequency as among the volunteers. This observation may indicate that this aberration is without pathologic significance. An obliquity like this may earlier have been incorrectly registered as an unilateral paresis of the pharynx (8).

An absence of the second movement of the epiglottis was more frequent among patients with dysphagia than among volunteers, 21 and 4 percent, respectively. Immobility of the epiglottis was seen only among dysphagial patients and then in 8 percent.

The swallowing center in the medulla, including the nucleus ambiguus, is responsible for the transmission of efferent motor activity. Any lesion in these centers might possibly induce an epiglottic dysfunction. However, this dysfunction seems to be rather circumscribed, an observation that suggests a lesion much nearer the effector organ, the epiglottis, than assumed above. It is possible that patients with extensive abnormalities in the act of swallowing, i.e., pharyngeal constrictor paresis, crico-pharyngeal incoordination and misdirected swallowing, may have a bulbar lesion while patients with circumscribed dysmotilities of the epiglottis more probably suffer from regional neuronal or muscular pharyngeal lesions.

The results from the present study indicate that it is possible to distinguish two different steps in *the closure of the vestibule*, both of which are clearly separated from the closure of the rima glottidis. In the first step the supraglottic space of the vestibule is closed by the apposition of the lateral walls (VII, Figs 2, 3, 4). This closure of the supraglottic space is caused by contraction and thickening of the superior portion of the thyroarytenoid muscle. The compressed supraglottic space has an orientation in the sagittal plane.

In the second step the closure of the vestibule is effected by a compression of the subepiglottic space from below (VII, Figs 2, 3). This is caused by the posterior aspect of the epiglottis with its superimposed fat cushion that gradually is pressed against the prominence of the ary region. The compressed subepiglottic space has an orientation nearly in the horizontal plane with its anterior part more caudally than the posterior. The tilting down of the epiglottis is probably due to a contraction of the thyroepiglottic muscles. A backward bulging of the superior - anterior wall of the vestibule is achieved by a folding of the median soft tissue linking the thyroid cartilage to the hyoid bone. This tissue comprises the epiglottic cartilage, the pre-epiglottic fat cushion and its bounding ligaments, namely, the thyroepiglottic, the median thyrohyoid and the hyoepiglottic ligaments. In analogy with other folds in this region the above structures have been designated "the median thyrohyoid fold" (39).

The described sequence of events in the closure of the vestibule by a compression from below - the supraglottic followed by the subepiglottic space - is important as it implies a peristaltic-like mechanism that can clear the vestibule from bolus material. After a swallowing act the vestibule is free from foreign particles when it opens again.

Defective closure of the laryngeal vestibule was more frequent among dysphagial patients than volunteers. It was also obvious that the defect when present was more profound among the former.

In volunteers the contrast medium did not reach further than into the subepiglottic space.

All the volunteers and all the dysphagial patients had a normal closing of the rima glottidis. However, an asymmetric closure was seen among 7 of the patients with unilateral palsy of the vocal folds. In none of these did the contrast medium reach into the trachea, indicating that the closure of the rima glottidis was not impaired.

The defective closure of the laryngeal vestibule during swallowing could be distinguished into two principally different categories. The first category was a delayed closure allowing entrance of contrast medium into the laryngeal vestibule. In the patients of this category the contrast medium often reached as far down as to the level of the vocal folds. However, when the vestibule finally closed its content of contrast medium was expelled out into the mesopharynx and in a few cases also into the trachea. The second category of faulty closing of the laryngeal vestibule was discerned as an inability to close - the vestibule remained partially open during the whole time elapse of swallowing. Contrast medium entered the vestibule and remained there until it was either aspirated or expelled by vigorous coughing.

The first category of faulty vestibular closing may be explained by a defect in the subtle normal timing of the long series of events involved in the act of swallowing. Even a very short delay in the closure of the laryngeal vestibule will promptly result in an entrance of contrast medium into the vestibule. If the vestibule remains open when the pharyngeal pressure increases, due to the pharyngeal constrictors, contrast medium will inevitably be pressed into the vestibule. The degree of delay in vestibular closure will determine how far down into the vestibule the contrast medium will reach on swallowing.

The second category of insufficient vestibular closure - an inability to close - may be explained by a lesion that involves the neuromuscular supply of the vestibule. The precise pathogenetic mechanism is unknown but could be supposed to be more profound than that causing a delayed vestibular closing.

An explanation of the observed aspiration of contrast medium between two swallowings could be defective or absent sensitivity in the vestibule. The vestibule is under normal conditions very sensitive and richly innervated by sensory fibers via the internal branch of the superior laryngeal nerve (38, 83, 84). In the normal individual sensory stimulation promptly results in vestibular closure mediated via efferent impulses from the swallowing center in the reticular formation of the medulla oblongata. A proposed theory of an impaired sensitivity is supported by the fact that many of these patients are unaware of their misdirected swallowing. When part of the bolus has entered the vestibule this does not ultimately imply that bolus material also reaches the trachea, as aspiration further down into the airways often is prevented by a forceful expiration. This was frequently seen in patients with entrance of contrast medium beyond the subepiglottic space. Simultaneously with the opening of the rima glottidis and supraglottic space they tried to get rid of the contrast medium by means of a forceful expiration or coughing before they started to inspire. This accessory mechanism seemed to be very effective in several patients.

Dysfunction of the cricopharyngeal muscle is dealt with in paper IV. During normal resting conditions the cricopharyngeal muscle is kept in a state of tonic contraction and serves as the upper esophageal sphincter. The tonic cricopharyngeal contraction prevents air from passing down from the pharynx to the esophagus on inspiration, and in patients with gastro-esophageal reflux the muscle acts as a barrier to prevent a further reflux of gastric content into the pharynx.

The first radiologic investigation concerning the frequency of dysfunction of the upper esophageal sphincter was performed by Macmillan in 1931 (67). He found "acute spasm at the entrance of the esophagus" in 13 patients among 921 examined with conventional technique due to dysphagia.

Crichlow examined a group of patients with complaints of dysphagia with cineradiography and reported that 62 percent of them

showed a cricopharyngeal indentation (30). The corresponding figure for the present investigation was 22 percent. However, Crichlow did not account for the selection of his material and his definition of cricopharyngeal dysfunction was wider than that used in this report.

Silbiger (93) examined 101 patients with different neuromuscular disorders and dysphagia with the aid of cineradiography. He found that 35 percent suffered from dysfunction of the upper esophageal sphincter. This figure is higher than that obtained in the present investigation (22 %). This discrepancy may be explained by a different selection of patients included in his investigation and that of the present study. Neither of these is any true investigation of the real incidence of cricopharyngeal dysfunction.

The histopathologic appearance of the muscle in patients with cricopharyngeal dysfunction has been studied by several authors who have claimed the muscle to be either normal, fibrotic, hypertrophic or hyperplastic (13, 32, 45, 65, 72, 85, 97). The hinderance for the passing bolus due to the cricopharyngeal indentation may vary. Even 1 patient with a complete obstruction has been reported (20).

Few reports have appeared concerning the frequency of cricopharyngeal indentation in individuals without swallowing complaints. Seaman in 1966 made a cineradiographic study of 200 individuals without dysphagia and reported that 5 percent had such an indentation (90). This report as well as the present investigation indicate that a cricopharyngeal indentation, suggesting a dysfunction, may be asymptomatic.

There was a considerable individual variation in the depth of the indentation of the muscle on the cineradiograms. The indentation also varied in one and the same patient from one swallowing to another. In many patients the indentation was only substantial during a very brief moment in the act of swallowing. This nonuniform appearance of the cricopharyngeal indentation may explain why an ordinary x-ray examination so often fails to

demonstrate the dysfunction. The reproducibility of the cricopharyngeal indentation was related to the size of the bolus, i.e., a small bolus often failed to distend the pharynx sufficiently to visualize the indentation. This may explain the difference in incidence reported by various authors. In the present investigation only 22 of the 55 cineradiographically demonstrable cricopharyngeal indentations could be detected on a conventional x-ray examination. These observations strongly stress the necessity of including a cineradiography of the act of deglutition in the routine examination of patients with dysphagia.

From the results of the present investigation it is evident that the cricopharyngeal muscle has two principally different functions. The first one is the sphincteric function. The second one is to participate in the coordinated and propulsive peristaltic contraction of the pharyngo-esophageal constrictors during deglutition. In cineradiography of normal individuals it is not possible to differentiate the cricopharyngeal muscle from the other constrictors during the act of swallowing. The cricopharyngeal muscle is recognized at first when the bolus has passed and the other pharyngo-esophageal constrictors have relaxed. Now it is seen only because it does not relax. On the contrary, it remains in tonic contraction. As earlier mentioned, the cricopharyngeal muscle relaxes already when the bolus enters the oropharynx, i.e., before the bolus has reached the pharyngo-esophageal junction. This explains why the cricopharyngeal muscle is never seen as an indentation in the gullet of normal individuals during deglutition (30).

The present investigation of patients with dysphagia has clearly shown that conventional single film technique is an inadequate method for the disclosure of cricopharyngeal dysfunction as only 40 percent of the instances were correctly apprehended.

The term 'cricopharyngeal achalasia' is often used in the literature to designate conditions where the relaxation of the cricopharyngeal muscle during swallowing is insufficient or delayed (23, 95). 'Achalasia' means "not relaxing" and therefore it

seems inappropriate to use this expression for conditions where the muscle in reality relaxes, even if this relaxation is delayed or incomplete. *Cricopharyngeal dysfunction* seems to be a more adequate denomination for this condition.

One patient was found to have a defective tonus in the cricopharyngeal muscle. The peristalsis travelled uninterrupted through the pharyngo-esophageal junction. However, the cricopharyngeal muscle did not remain contracted but relaxed together with the adjacent segments of the gullet when the bolus had passed. This entity, called *chalasia of the upper esophageal sphincter*, has been reported to appear in only one condition - myotonic dystrophy (59, 92). Our patient had no signs of this condition.

Esophageal webs have been dealt with in paper IX. The presence of *cervical esophageal webs* among nondysphagial individuals has been investigated by conventional single-film technique and assessed to vary between 0 and 1 percent (27, 36, 99). These figures are in accordance with the results from the cineradiographies among the volunteers (0.7 %). The incidence of webs among patients with dysphagia has been estimated to vary between 7 and 14 percent when the patients were examined by single film technique. When the examinations have been performed with the aid of cineradiography the incidence has been found to be 17 percent (96). These figures are also in accordance with the figures obtained in the present investigation. Whether or not cervical esophageal webs cause dysphagia has been disputed. In some reports the webs have been claimed to be insignificant (21, 28, 70, 79, 91). Others have claimed that webs can cause dysphagia (36, 37, 51, 60, 68, 71, 99, 100).

The present study has clearly shown how precarious the diagnosis of cervical esophageal webs really is. Even if the patient is swallowing a large bolus the web may escape detection especially on single-films. Even on the cinefilms it was obvious that both AP and lateral projections were valuable in detecting the webs, i.e., a thin oblique web could be overlooked in the lateral projection and be well visible in the AP projection.

On cineradiography the webs often revealed themselves as temporary phenomena visible for only a fraction of the time during which the cervical esophagus was filled with contrast medium. In many patients webs are formed in the esophagus only if a fairly large contrast bolus is passing down the gullet. A smaller contrast bolus fails to induce the formation of a web (36, 82, 98). These observations explain why the careful routine examination with films taken during barium swallowing in 12 patients failed to visualize webs that were easily detected by cineradiography.

Even when the routine examinations are performed properly with swallowing of a large bolus of contrast medium the webs may baffle detection. This was reflected in the present investigation where 15 of the 38 webs (39 %) on cineradiography were seen as transient phenomena during a short moment of the act of swallowing.

From the results of this examination it can be concluded that the presence of webs never can be excluded from even the best single "swallowing" films.

The presence of Zenker diverticula among the patients was in accordance with Macmillan's investigation (67, 68). Of the presented functional or morphodynamic abnormalities of the hypopharynx Zenker diverticula are those abnormalities least probably overlooked even on single-film examinations. When a small diverticulum is present its differentiation from a pseudodiverticulum, i.e., contrast medium retention above an indentation due to a cricopharyngeal dysfunction, can be spurious on single films. Cineradiographically the true diverticulum enlarges when the pressure in the pharynx rises on the passage of the bolus. A pseudodiverticulum is, on the contrary, effaced during the same conditions as it is dependent only on the indwelling of the cricopharyngeal muscle which at the peak of the deglutition usually relaxes. The potential transition of pseudodiverticula into true Zenker pouches has been debated (18, 31, 33, 44, 47-49, 78). From the present study no conclusions can be drawn about such a transition (IV).

The present investigation has shown that functional abnormalities in the pharyngeal stage of deglutition frequently occur concomitantly, i.e., two or more abnormalities were registered among 52 percent of the patients (Table 4). Concomitant abnormalities were most frequent among patients with pharyngeal constrictor paresis (100 %), epiglottic dysfunction (86 %) and defective closure of the vestibule (77 %). This is in contrast to the conditions among the volunteers in whom two abnormalities were registered in only 1.3 percent. This may indicate that the presence of one circumscribed functional abnormality can be compensated and thereby not cause dysphagia. However, when two or more functional abnormalities are present this is likely to give dysphagia.

The present investigation has shown that cineradiography in the majority of dysphagial patients can disclose functional abnormalities in the pharyngeal act of swallowing. Conventional radiographic technique often fails to give a proper diagnosis in dysphagial patients. Among patients with cineradiographic criteria for cricopharyngeal dysfunction the diagnosis had been overlooked on the conventional films in 60 percent of the patients. The corresponding figure for cervical esophageal webs was 32 percent. Regarding circumscribed pharyngeal constrictor musculature paresis no figures are available, but it is clear that the diagnosis in most cases would have been overlooked on the conventional films. On conventional radiograms the diagnosis is ultimately based on such indirect signs as retention of contrast medium and misdirected swallowing. Regarding epiglottic dysfunction it is obvious that single-film examinations cannot disclose the movement pattern. Fluoroscopy is difficult as the movement of the epiglottis is rapid. Regarding defective closure of the laryngeal vestibule it is obvious that defects of the first category, i.e., when the contrast medium was completely expressed from the vestibule on the complete but delayed closure, is difficult to detect on single-films as these must be obtained during that particular moment when the contrast medium is within the vestibule. In defective vestibular closure of the second category it should be possible to observe the remaining remnants

of contrast medium in the vestibule even on single-films. However, the estimation of the particular events leading to the contrast medium entrance cannot be detected on single-films and a differentiation from aspiration between two swallowings is thereby impossible.

GENERAL SUMMARY AND CONCLUSIONS

The present investigation has shown that 83 percent of individuals without dysphagia have a pharyngeal stage of deglutition that was accomplished in a standardized way. This involved the passage of the bolus through the gullet with the aid of a symmetric and uninterrupted contraction in the pharyngeal constrictor musculature. The cricopharyngeal muscle was relaxed on the passage of the bolus, but also took part in the peristaltic wave together with the pharyngeal constrictors. The airways were protected during swallowing by an obturation of the rima glottidis, a closure of the vestibule and by a tilting down of the epiglottis. The closure of the vestibule was accomplished in a two-step fashion with a peristaltic-like compression from the level of the rima glottidis. In the same way the tilting down of the epiglottis was effected in a two-step way. The first movement occurred from the resting upright position to the transversal position synchronously with the elevation of the hyoid bone and the larynx.

Among individuals without swallowing complaints 17 percent had aberrations from this regular pattern. In 4 percent the epiglottis attained an obliquity of 30-90 degrees in the AP projection when tilting down. In 5 percent the epiglottis tilted down to the transversal position, but not further down. In 5 percent the closure of the laryngeal vestibule was defective whereby contrast medium reached into the subepiglottic space. A defective relaxation of the cricopharyngeal muscle was registered among 4 percent, while a cervical esophageal web was encountered in 1 of the volunteers.

Among patients referred for radiologic examination of the pharynx

and esophagus due to dysphagia a regular pattern of swallowing was observed in 20 percent, whereas functional and morphodynamic abnormalities were registered in 80 percent. A paresis of the pharyngeal constrictor musculature of varying severity and extension was observed in 10 percent. In 41 percent a defective closure of the vestibule was registered. This was due to a defective closure of the subepiglottic space in 23 percent and of the subepiglottic and supraglottic spaces in 16 percent. A dysfunction of the epiglottis was observed among 33 percent. In 4 percent the epiglottis attained an obliquity of 30-90 degrees in the AP projection. An absence of the second movement of the epiglottis was registered among 21 percent, while the epiglottis was immobile in 8 percent. A defective relaxation of the cricopharyngeal muscle was observed among 22 percent. This was registered as an indentation of varying size in the posterior wall of the pharyngo-esophageal junction when the cervical esophagus was dilated by the bolus. In 14 percent the indentation was transient while in 8 percent it was continuous throughout the swallowing act. Of these cricopharyngeal indentations 40 percent could be discerned as such on the conventional single-films. A web formation in the pharyngo-esophageal junction area was registered in 20 percent of the women and 8 percent of the men. Of the webs 68 percent could be detected as such on the conventional single films. Of the patients with webs 13 percent had also a malignant lesion in the pharynx/larynx or upper gastrointestinal tract. In 2 percent a Zenker diverticulum was registered in the posterior wall of the pharyngoesophageal junction.

Among the volunteers 2 had both epiglottic dysfunction and a defective closure of the laryngeal vestibule. In 52 percent of the patients with dysphagia more than one functional abnormality was registered. Concomittant abnormalities was most frequent among patients with pharyngeal paresis (100 %), epiglottic dysfunction (86 %) and defective closure of the vestibule (77 %):

The results of the present investigation has confirmed that cineradiography is a suitable radiologic method for studying normal and abnormal deglutition. In normal individuals the pharyngeal stage of deglutition is executed with precision,

smoothness and obviously with efficiency. In a few individuals without swallowing complaints circumscribed functional aberrations can be registered.

In patients with dysphagia high-speed cineradiographic examination can in the majority of the patients disclose functional abnormalities during deglutition. It is therefore indispensable to examine dysphagial patients with this technique during pharyngeal deglutition in order to discover a probable explanation to their complaints.

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CINERADIOGRAPHY OF THE PHARYNGEAL STAGE OF
DEGLUTITION IN 150 INDIVIDUALS WITHOUT DYSPHAGIA

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All patients who are referred to the Department of Diagnostic Radiology of Malmö General Hospital because of dysphagia are in addition to the routine examination also subjected to cineradiography of the pharyngeal stage of deglutition. The evaluation of the cineradiograms obtained in this way was sometimes made difficult by indistinct concepts about normal and abnormal patterns of deglutition.

The purpose of this investigation was to perform a cineradiographic study of the act of swallowing in a group of non-dysphagial volunteers in order to find out the range of radiographic patterns of normal deglutition.

MATERIAL AND METHODS

Patients referred to the Radiological Department for examination with barium meals, i.v.p. etc, were asked to participate in this study. The type of radiographic examination among the patients varied as seen in Table I. Seven healthy staff members were also included. The volunteers were interviewed and asked particularly about any earlier or present dysphagia. All patients with the slightest suspicion of swallowing difficulties were excluded from the study. There were a total of 150 individuals (79 men and 71 women with a mean age of 52.5 and 51.1 years, respectively, range 20-82 and 20-79).

The cineradiograms were obtained with the aid of a Camématic GV 16-mm film camera (Brevets Countant-Mathot) and a Philips cine-pulse unit mounted on a 9"/5" x-ray image intensifier (Cesiumiodine, Philips XG 2010/20).

Table I

Type of radiologic examination among 143 patients who subsequently volunteered for cineradiographic examination of the pharyngeal stage of deglutition. No patients with dysphagia were included.

Type of examination	Number of patients
Barium examination of stomach and duodenum	69
Peroral cholecystography	50
Positive contrast herniography	12
Barium examination of small bowel	7
IVP	3
Skeletal examination	2

The film used was Gevapan 36 (negative film). The distance between the x-ray tube and the input screen was 115 cm. The exposures were made at between 70 and 80 kV with a pulse time of 1,3 or 5 msec and with a maximum tube current of 130 mA. The cinefilms were analyzed on a Steenbeck Analector (ST 1100 W) permitting a frame by frame analysis.

The volunteers were examined with at least one AP and one lateral projection, each including swallowing of a large mouthful of barium contrast medium (60 % w/w) followed by several secondary swallowings to clear the pharynx. The cinefilms were obtained with a speed of 50 or 100 frames per second.

In the analysis the following events were scrutinized: behaviour of the soft palate, formation of Passavant's ridge, the behaviour of the pharyngeal constrictors, the movements of the epiglottis, obliquity of the epiglottis during its swallowing movements more than 30° , entrance of contrast medium into the laryngeal vestibule and into the trachea, the activity of the cricopharyngeal muscle, presence of webs and Zenker's type of diverticula in the posterior wall of the cervical oesophagus.

RESULTS

In 124 individuals (83 % of the total material) the cineradiographies disclosed a synchronous series of events and showed a symmetric pattern of deglutition. The swallowing act could principally be divided into different steps and followed a certain course of events (Fig. 1).

The bolus was passed from the oral cavity into the pharynx through the fauces pharyngis by a backwards sweeping movement of the tongue. The tongue was then held in the backward position. The posterior part of the tongue was by a superior and posterior movement, pressed against the palate and the pharyngo-palatineal plicae.

Concurrently with the backward movement of the tongue the epipharynx was shut off from the mesopharynx by an apposition of

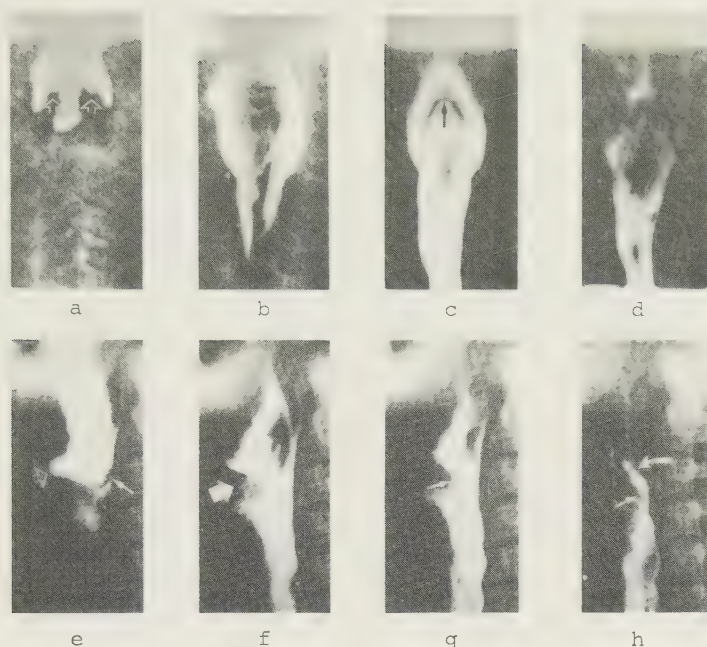


Fig. 1. Cineradiographic sequence of normal pharyngeal stage of deglutition. a-d. AP projection. e-h. Lateral projection. During the passage of the bolus the epiglottis (thin arrow) is tilted down. The valleculae (open arrow) are effaced. There is a peristaltic contraction of the mesopharynx (bent arrow). No contrast medium enters the closed vestibule (thick arrow).

the soft palate to the posterior wall of the pharynx. The soft palate formed a cranio-convex vault while the posterior pharyngeal wall was seen to bulge forwards (Passavant's ridge). Synchronously with the backward movement of the tongue and the closing of the epipharynx the hyoid bone was lifted upwards in a posterior and superior direction together with the larynx. During this movement the larynx approached the hyoid bone. The rima glottidis was closed. The epiglottis attained a horizontal position - first movement. The pharyngeal constrictor muscles contracted and the

bolus was propelled down the pharynx by a peristaltic stripping wave. The hyoid bone then moved in an anterior and superior direction. The epiglottis tilted down with its tip reaching into the esophageal inlet - second movement.

The laryngeal vestibule was closed in a two-step fashion. The inferior (supraglottic) portion was closed by an apposition of the lateral walls of the vestibule while the superior (subepiglottic) portion was compressed in a superior - inferior direction by an apposition of the base of the epiglottis to the ary region when the epiglottis was tilted down into the esophageal inlet.

When the bolus reached the cricopharyngeal area no indentation or narrowing of the pharyngo-esophageal junction was observed. The peristaltic wave passed the cricopharyngeal region uninterrupted on its way from the pharynx to the esophagus. When the peristalsis had passed, the cricopharyngeal muscle remained contracted as an upper esophageal sphincter while the gullet superior and inferior to the cricopharyngeal region relaxed.

At the end of the swallowing act the larynx descended and the epiglottis tilted back into its resting upright position. The tongue was moved forwards.

The above observed sequence of events was rather constant but a few variations could be observed. For instance, the closure of the rima glottidis was observed to start either at the beginning of the elevation of the larynx or later. However, the rima closed always before the bolus reached the valleculae region. Closure of the supraglottic portion of the vestibule could take place either before the epiglottis tilted down to the horizontal position - first movement - or later in the swallowing act. However, it was not observed to occur after the epiglottis had attained its downwards directed vertical position - second movement. This second movement of the epiglottis could occur either early in the swallowing act as a succession of the first movement of the epiglottis and before the closure of the subepiglottic segment of the laryngeal vestibule took place. This final tilting down of the epiglottis did not occur after the stripping wave had passed.

The time required for some of the movements in the swallowing act to occur was measured among 10 volunteers and calculated to be as follows: The apex of the bolus passed from the pharyngeal fauces to the cricopharyngeal muscle in 28/100 second (range 20 - 44). The first movement of the epiglottis, i.e., the tilting down of the epiglottis from its upright position to its transversal position, took place in 16/100 second (range 8 - 24). The second movement of the epiglottis, i.e., the tilting down from the transversal position to the downwards directed position, took place in 20/100 second (range 14 - 28). The tilting back to its upright position of the epiglottis took place in 22/100 second (range 12 - 34).

In 26 individuals different aberrations from the above described symmetric and synchronous pattern were registered (Table II). In the AP position 6 individuals showed obliquity of the epiglottis between 30° - 90° during the second movement, i.e., when the epiglottis tilted down from the transversal to its vertical position (Fig. 2).

Type of aberration	Number of patients	
Epiglottis dysmotility		
obliquity $45-90^{\circ}$	6	13 (8.6 %)
absence of first movement	7	
Contrast medium entrance into the subepiglottic segment of the laryngeal vestibule	8	8 (5.3 %)
Cricopharyngeal dysfunction	6	6 (4 %)
Esophageal web	1	1 (0.7%)

Table II

Type of aberrations from a symmetric and synchronous pattern of the swallowing act among 150 volunteers without dysphagia examined by cineradiography of the pharyngeal stage of deglutition.

In 7 patients the second movement of the epiglottis was conspicuous by its absence (Fig. 3). There was no preponderance for any age group according to the two mentioned epiglottic dysmotilities. However, they were more frequent among men than women (10% and 2.8 %, respectively). In 5 individuals this epiglottic dysmotility was the only aberration registered.

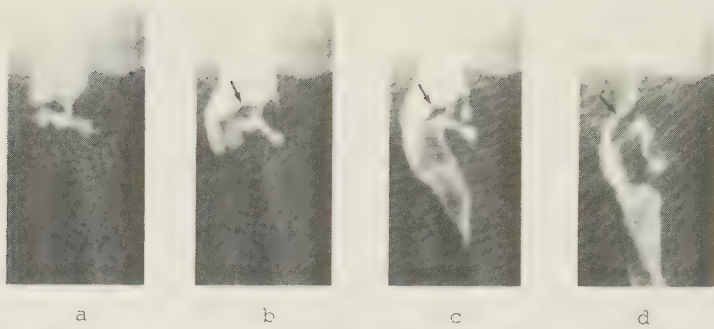


Fig. 2. Cineradiographic sequence. AP projection. The epiglottis (arrow) attains an obliquity of 45° . The obliquity is only slight in b but is about 60° in d.

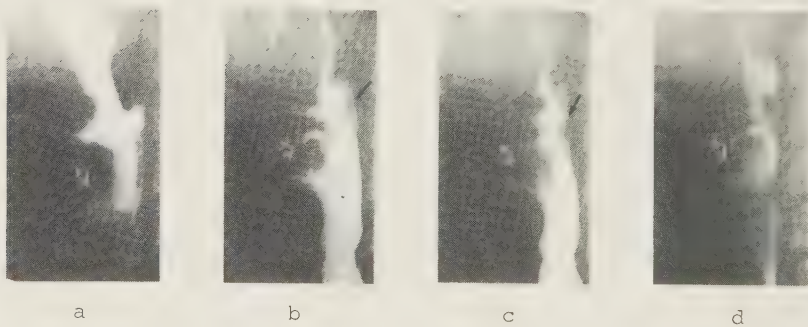


Fig. 3. Cineradiographic sequence. Lateral projection. The epiglottis does not fulfill its final tilting down but remains in the transversal position. Tip of the epiglottis (thin arrow). There is a defective closure of the vestibule. This can be seen as air in the vestibule in a and as entrance of contrast medium in b-d (thick arrow). At the end of the swallowing the vestibule is closed and the contrast medium expressed into the mesopharynx.

In the remaining 2 individuals moderate amounts of contrast medium passed into the laryngeal vestibule and an absence of the second stage of epiglottic movement was also registered.

Misdirected swallowing, i.e., contrast medium passing into the laryngeal vestibule, was observed in 8 volunteers (6 men and 2 women) (Fig. 3). Contrast medium was never seen to pass to a level below the subepiglottic segment of the laryngeal vestibule, hence, no contrast medium reached the rima glottidis or the trachea. In all but the 2 individuals accounted for above with dysfunction of the epiglottis, the misdirected swallowing was the only aberrant finding.

An indentation in the posterior wall of the pharyngo-esophageal junction, apparently due to the cricopharyngeal muscle, was registered in 6 volunteers (2 men and 4 women) (Fig. 4). The indentation was seen when the bolus distended the cervical segment of the esophagus. Among these individuals there was no concomitant abnormality. The indentation due to the cricopharyngeal muscle did not exceed half of the diameter of the adjacent gullet. In 4 of these patients the cricopharyngeal indentation remained visible during the course of contrast medium passage. In the remaining 2 it was a transient phenomenon during the initial part.

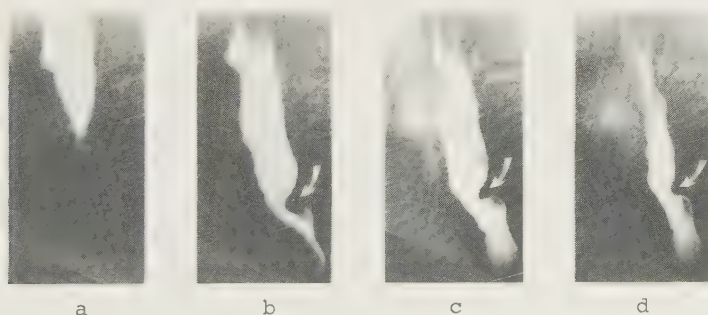


Fig. 4. Cineradiographic sequence. There is an indentation in the posterior wall of the pharyngo-esophageal junction (bent arrow) due to an incoordinated relaxation of the cricopharyngeal muscle which does not completely relax.

A web was seen in the anterior aspect of the upper esophagus in a 65-year-old woman. This web was not concomitant with any other abnormality.

No individuals exhibited any impairment in the motility of the soft palate, Passavant's ridge or pharyngeal constrictor muscular activity.

DISCUSSION

The first to examine the act of swallowing with radiography were Cannon and Moser in 1898. They used subnitrate of bismuth as a contrast medium and studied different animals and also a 7-year-old girl by fluoroscopy. They merely focused on the time required for the bolus to travel from the mouth to the esophagus and claimed that this took place in a fragment of a second. They also claimed that the bolus was thrown from the mouth into the mid thoracic esophagus by a vigorous contraction of the mylohyoid muscle.

Cineradiographic reports of deglutition appeared successively and in 1951 Saunders et al. published their study on 7 patients examined with a film-speed of 30 and 60 frames per second. Since then several reports on deglutition studied by cineradiography, have appeared. Ramsey et al. (1955) reported on 300 examinations of which 150 were considered to be normal.

The present study was initiated by a great need for a distinct delineation of normal and aberrant radiographic patterns of swallowing. The study was performed in order to obtain a control material to be used as a reference in the evaluation of cineradiograms of patients with dysphagia.

By comparing the cineradiograms of dysphagial patients with those of the volunteers without dysphagia it would be possible to define the pathologic significance of even small circumscribed isolated aberrations in the swallowing act.

It has long been claimed that the epiglottis did not tilt down during deglutition (Anderson and M'Cormick 1891/1892, Negus 1927)

and this statement has been generally accepted (Gray's Anatomy 1962). However, today the valid opinion is that the epiglottis is tilted down, its tip is brought down to the inlet of the esophagus during deglutition (Fink et al. 1979).

This series indicates that aberrations from the symmetric pattern of deglutition can occur in individuals without swallowing complaints. Six volunteers showed an obliquity of the epiglottis during its second movement from its transversal position to its final inverted position in the esophageal inlet. This kind of obliquity of the epiglottis has been regarded as due to unilateral paresis of the pharynx (Ardran and Kemp 1967, Silbiger et al. 1968).

In the 6 volunteers it was clearly seen that the oblique epiglottis diverted the stream of contrast medium to that pharyngeal side where the epiglottis was tilted down most efficiently. This phenomenon could well have been misinterpreted as unilateral pharyngeal paresis by earlier authors. However, in the present investigation the obtained cineradiograms of the mentioned 6 volunteers showed a complete normal pharyngeal muscular activity without any signs of paresis.

The protection of the airways is due partly to the tilting down of the epiglottis. However, a more effective part of this protection is given by the closure of the rima glottidis and the vestibule. The latter is closed off from the pharynx in a two-step manner.

Several earlier cineradiographic reports have claimed that part of the bolus may pass into the laryngeal vestibule, sometimes even into the trachea, and that this may be a normal finding (Ardran and Kemp 1952, Bachman 1959, Ramsey et al. 1955). The results of the present investigation suggest that it is abnormal for any part of the bolus to pass into the laryngeal vestibule during swallowing as this was only seen in a few volunteers. In these only a minor amount of contrast medium reached the subepiglottic portion of the vestibule. It is definitely abnormal if any part of the bolus passes into the supraglottic segment of the

laryngeal vestibule.

Several authors have claimed that it is abnormal to have an indentation in the posterior wall of the pharyngo-esophageal junction due to the cricopharyngeal muscle at a moment when the cervical esophagus is dilated by the bolus. It has been interpreted as due to achalasia of the muscle and that this gives rise to dysphagia in these patients (Asherson 1950, Crichlow 1956, Sutherland 1962). However, Asherson reported individuals without swallowing complaints who had a typical indentation in the posterior wall of the pharyngo-esophageal junction. He described these patients as "latent cases of cricopharyngeal achalasia". The results of the present series indicate that his observations are correct, i.e., an indentation of the cricopharyngeal muscle is not necessarily combined with swallowing difficultis.

From observations of the cineradiograms in this series it became clear that the cricopharyngeal muscle, or at least its transverse portion, had two defined and separate functions. The first function was as a superior esophageal sphincter. The second function was to participate in the peristaltic stripping wave. This wave transversed and included the cricopharyngeal muscle in all the volunteers.

The coexistence of aberrations from the symmetric pattern of deglutition among the volunteers in this report suggests that the act of swallowing, within certain limits, is not absolutely regular and its different movements not always consecutive. It is also possible that the aberrations registered were accidental. However, the aberrations appeared unchanged on repeated swallowings and this observation indicates that they were not of an accidental type. A probable explanation of these aberrations from the symmetric pattern of deglutition may be the presence of minor lesions in the peripheral nerves or in the muscles. At the first appearance of these circumscribed and isolated dysfunctions a very slight and transient dysphagia may be felt by the patient. However, small aberrations in the act of swallowing may easily be compensated by the patient. It is well known that even rather

extensive dysfunctions have been reported to cease spontaneously or with training (Ardran et al. 1957).

Although the results of the present study confirm previous observations about a symmetric and regular pattern in the swallowing act, the different events during this act could occur with somewhat varied timing. This can vary but only to a certain limit beyond which the act of swallowing alters more profoundly. For instance, a delayed closure of the subepiglottic portion of the vestibule will lead to bolus entrance. In the same way a late relaxation of the musculus cricopharyngicus will appear as an indentation in the posterior wall. A considerable variation in the time for the epiglottis to fulfill its movements was also found, but also in the time for the apex of the bolus to transverse from the pharyngeal fauces to the level of the cricopharyngeal muscle. It may well be that every person has a specific pattern of deglutition which by small but definite variations can be distinguished from that of other individuals.

ABSTRACT

With the aid of cineradiography the pharyngeal stage of deglutition was examined with a speed of 50 and 100 frames per second among 150 individuals without dysphagia. In 124 (83 %) the act of swallowing had a symmetric and synchronous pattern. Different types of aberrations from this pattern were registered in 26 individuals (17 %). In 7 individuals the epiglottis did not tilt down properly but remained in a transversal position during deglutition. Eight individuals had contrast medium pass into the laryngeal vestibule. Seven individuals had a dysfunction of the cricopharyngeal muscle which did not relax properly. One individual had a web in the upper esophagus. In all but 2 individuals the aberrations were isolated and not concomitant with other abnormalities in the act of swallowing.

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CINERADIOGRAPHY OF THE PHARYNGEAL STAGE OF DEGLUTITION IN 250
PATIENTS WITH DYSPHAGIA.

Olle Ekberg, M.D. and Göran Nylander, M.D.

Radiographic examination of the swallowing act with the aid of conventional single film technique is well suited to disclose the presence of morphological lesions. However, in patients with dysphagial complaints this technique is insufficient as it does not reflect functional disturbances in the act of swallowing. For this reason all dysphagial patients referred to the X-ray Department of Malmö General Hospital in addition to the conventional pharyngoesophageal study are also subjected to a cineradiography of the swallowing act. The purpose of this report is to describe different functional disorders in the swallowing act as revealed by cineradiography of patients suffering from dysphagia. This subject does not seem to have been properly covered in the pertinent literature and therefore warrants a report.

MATERIAL AND METHODS

The material was obtained from patients with dysphagia referred for radiographic pharyngoesophageal examinations. There were 103 men and 147 women with an age between 18 and 95 years (mean 61 years). It consisted of 250 consecutively performed cineradiograms of the pharyngoesophageal act of swallowing in the same number of patients during a two-year period.

The patients were first examined with conventional single-film technique including plain films and films during barium swallowing obtained in the PA and left lateral projections. The films after barium swallowing were taken in lateral, PA, LAO, and RAO projections. The cineradiograms were obtained with the aid of a high-speed camera (Camématic GV Super, from Brevets Countant-Mathot) which was mounted on an x-ray image intensifier and a Philip cine-pulse unit. The cineradiographic examinations included repeated film-series during swallowing of a large mouthful of barium contrast medium (Barytgen^R 60 % w/w) followed by several secondary swallowings. Cineradiograms were obtained in the AP and lateral projections. The films obtained were analyzed by the aid of a Steenbeck analector allowing a frame by frame analysis.

The cineradiograms were scrutinized concerning the following morphodynamic and functional details of deglutition:

- ability of the palatopharyngeal sphincter (Passavant's ridge) and the soft palate.
- ability of pharyngeal constrictor musculature
- epiglottic motility, i.e., the first movement of the epiglottis from the upright to the transversal position and its second movement from the transversal to the inverted position with its tip in the esophageal inlet (Ekberg and Nylander)
- obliquity of the epiglottis at swallowing (more than 30°).
- misdirected swallowing
- indentation due to the cricopharyngeal muscle in the posterior wall of the pharyngoesophageal junction
- presence of webs and diverticula.

RESULTS

In 200 (80 %) of the 250 dysphagial patients functional disturbances of different sorts were discovered in the act of swallowing. In the remaining 50 (20 %) patients a normal swallowing act was revealed by the cineradiograms, i.e., no morphologic or functional changes were discovered.

A complete pharyngeal constrictor palsy was observed in 6 patients and a circumscribed paresis of a defined segment of the constrictors was registered in 19 (Fig. 1 Table I). Among the latter a defective formation of the Passavant's ridge was seen in 2 who also had paresis confined to the superior portion of the constrictor pharyngeal muscle.

A dysfunction of the epiglottis was seen in 83 patients (33 %). Nineteen (8 % of the total material) of these had a completely immobile epiglottis (Fig. 1). Fiftythree patients (21 % of the total material) had a normal first epiglottic movement but failed to execute its second movement from the transversal position to the inverted position with the tip in the esophageal inlet (Fig. 2). In eleven patients (4 % of the total material) an asymmetric movement of the epiglottis was observed as it

Type of lesions/abnormalities	Number of patients	Percentage of 250
Paresis of the pharyngeal constrictors	25	10
Contrast medium entering into the laryngeal vestibule	103	41
Into subepiglottic space	58	
Into subepiglottic and supraglottic space	41	
Aspiration to trachea from the pharynx	4	
Epiglottic dysfunction	83	33
Obliquity during large bolus swallowing	11	
Absence of 2 nd movement	53	
Immobility	19	
Cricopharyngeal dysfunction	56	22
Webs	38	15
Zenker diverticula	5	2

Table I

Cineradiographic abnormalities among 250 dysphagial patients.

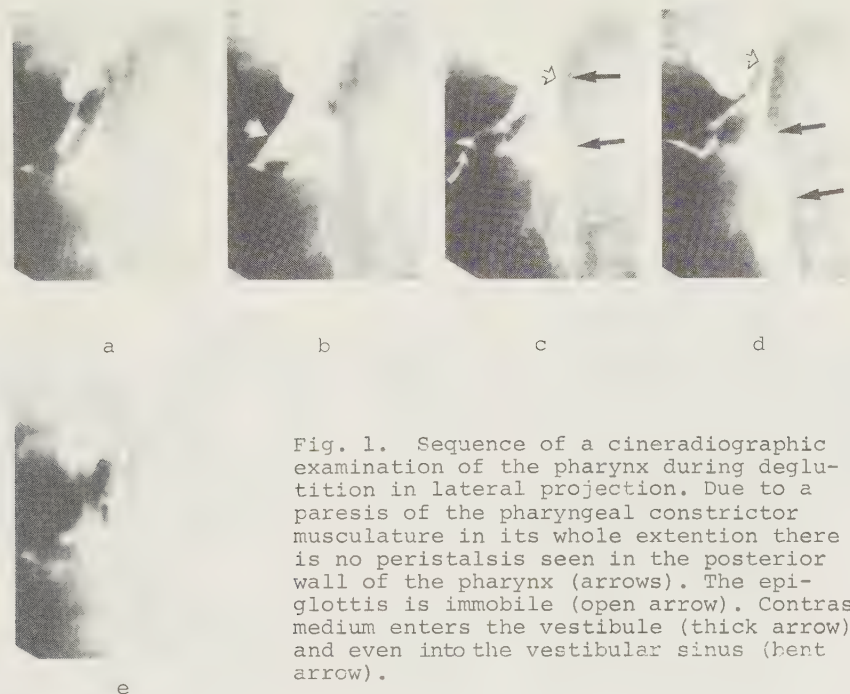


Fig. 1. Sequence of a cineradiographic examination of the pharynx during deglutition in lateral projection. Due to a paresis of the pharyngeal constrictor musculature in its whole extension there is no peristalsis seen in the posterior wall of the pharynx (arrows). The epiglottis is immobile (open arrow). Contrast medium enters the vestibule (thick arrow) and even into the vestibular sinus (bent arrow).

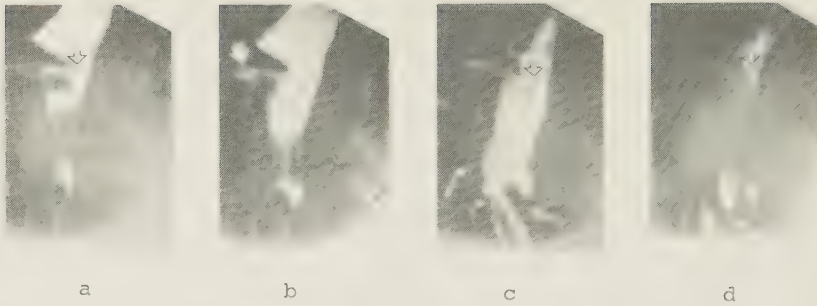


Fig. 2. Sequence of a cineradiographic examination of the pharynx during deglutition in lateral projection. The epiglottis (open arrow) is tilted down to the transversal position, but is not tilted further down with its tip into the esophageal inlet. Contrast medium reaches into the vestibule (thick arrow) and even into the trachea (bent arrow). There is a defective relaxation of the cricopharyngeal muscle (arrow) and above this indentation there is a "pseudodiverticulum" (arrow head). In the pharyngo-esophageal junction there is a webformation (thin arrow head).



Fig. 3. During deglutition the epiglottis (arrow) attains an obliquity with its right portion more caudal than its left.

tilted down to the inverted position; as seen in the AP projection the epiglottis attained an obliquity of 30° - 90° in these patients (Fig. 3).

A misdirected swallowing with contrast medium entering the laryngeal vestibule was seen in 103 of the patients (41 %). In 58 of these (23 % of the total material) the contrast medium reached only the superior (subepiglottic) portion of the vestibule, while in 41 (16 % of the total material) it also reached the lower (supraglottic) portion (Figs 1 and 2). In 31 of this last group of patients (12 % of the total material) the contrast medium also passed into the trachea from the supraglottic segment of the vestibule. In four patients contrast medium had reached into the vestibule between two swallowings.

Dysfunction of the cricopharyngeal muscle (incoordinated relaxation or achalasia), seen as an indentation in the posterior wall of the pharyngoesophageal junction when the cervical segment of the esophagus was well dilated by the bolus, was registered in 55 patients (22 %) (Figs 2 and 4). An absence of the sphincteric function of the muscle (chalasia) was seen in one patient who also had epiglottic dysfunction and misdirected swallowing.

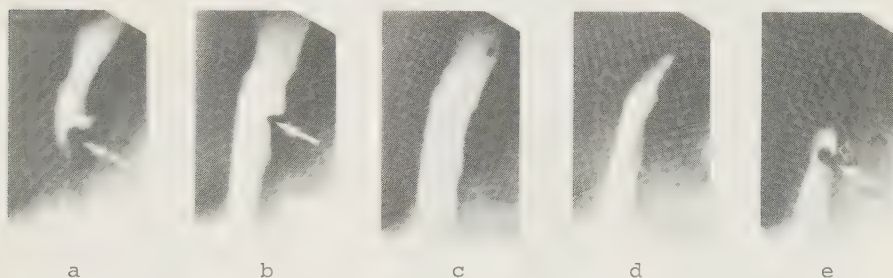


Fig. 4. Sequence of a cineradiographic examination during deglutition. Lateral projection. An indentation (arrow) in the posterior wall of the pharyngoesophageal junction is seen during the early stage of the act of deglutition when the apex of the bolus reaches the esophageal inlet (a). This indentation diminishes in size but does not efface even when the cervical esophagus is dilated by the passing bolus (b). However, somewhat later in the act of deglutition the indentation is effaced (c and d). When the bolus has passed the indentation due to the cricopharyngeal muscle is seen again (e). There is some retention of contrast medium (open arrow) above the indentation (e).

Webs in the cervical esophagus were seen in 38 patients (15 %) and in 4 of these there were two webs (Figs 2 and 5). In 5 patients (2 %) a Zenker diverticulum was encountered (Fig. 6).

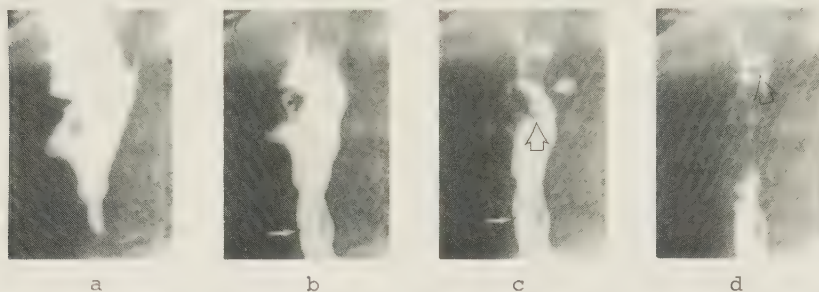


Fig. 5. Sequence of a cineradiographic examination during deglutition. Lateral projection. There is a small web (arrow) in the anterior wall of the cervical esophagus. The epiglottis is bent down to its transversal position but not further (open arrow). There is normal peristaltic activity in the pharyngeal constrictor musculature as can be seen in the posterior wall of the pharynx (thick arrows).

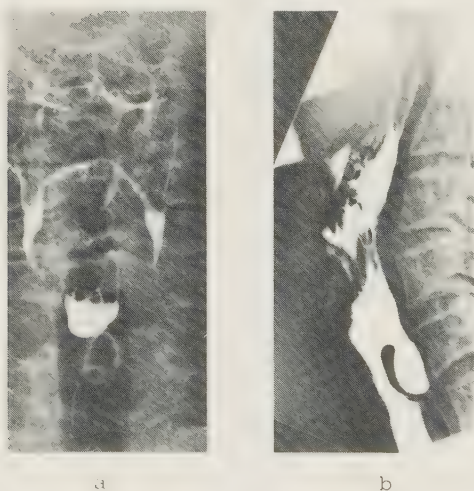


Fig. 6. Zenker diverticulum. (a) AP projection, (b) lateral projection.

Five patients had been treated by myectomy or myotomy of the cricopharyngeal muscle prior to the cineradiographic examination. These patients exhibited a varying degree of deformity in the pharyngoesophageal junction area. Ten patients had had surgical and/or radiologic therapy because of malignant lesions in the throat or neck region and they had varying degrees of deformities in the pharynx. These ten patients exhibited different forms of abnormalities in the act of swallowing as are summarized in Table II. One patient had a known tumour in the right piriform sinus which had not been treated prior to cineradiography. This patient had also dysfunction of the epiglottis and a defective closure of the laryngeal vestibule. No previously unknown neoplasm was encountered in this series.

Table II

	Paresis of pharyngeal constrictors	Misdirected swallowing	Epiglottic dysfunction	Cricophar- yngeal dysfunction	Web
Earlier myotomy or myectomy of the cricophar- yngeal muscle n = 5	0	5	4	2	1
Earlier surgical treatment other than above and radiotherapy n = 10	2	8	6	2	2

Functional abnormalities in the act of swallowing in patients earlier operated or treated with radiotherapy in the throat or neck region.

	Paresis of pharyngeal constrictors n = 25	Misdirected swallowing n = 103	Epiglottic dysfunc- tion n = 83	Cricophar- yngeal dys- function* n = 55	Webs n=38	Zenker diverticula n = 5
Paresis of pharyngeal constrictors n = 25	0 ^x	23	25	8	3	0
Misdirected swallowing and aspiri- nation 23 n = 103	23	24 ^x	65	23	15	2
Epiglottic dysfunction n = 83	25	65	12 ^x	17	8	1
Cricophar- yngeal dys- function* n = 55	8	23	17	20 ^x	18	1
Webs n = 38	3	15	8	18	13 ^x	1
Zenker diverticula n = 5	0	2	1	1	1	2 ^x

* one patient with ~~chelaesia~~ is not included

^x Patients with an isolated abnormality of the type indicated in the headings
n=71 (28%)

Table III

Functional abnormali-
ties in the act of
swallowing according
to the presence or
absence of concomi-
tant abnormalities.

Of the 250 patients 200 showed an aberrant pattern of swallowing. Seventy-one (28 %) exhibited an isolated functional abnormality while 129 (52 %) had two or more functional abnormalities (Table III).

DISCUSSION

Patients who seek medical advice for complaints of dysphagia are generally referred to an x-ray examination of the pharynx and esophagus. These patients will regularly be subjected to conventional single-film examinations of the hypopharynx and esophagus. A properly performed examination according to this method also includes swallowing studies with films exposed at a moment when a contrast medium bolus is passing down the gullet. This technique is well suited to disclose morphologic lesions and possibly also morphodynamic changes like webs and diverticula. However, when the aim of the examination is to disclose functional abnormalities the diagnostic conditions are quite different as it is impossible to evaluate the functional status of the pharynx from a conventional single-film examination (Bachman 1959; Scatliff and Scibetta 1963).

Examinations of the swallowing act in a defined group of patients with x-ray technique have been sparsely reported. In 1931 Macmillan reported on such an investigation of 921 patients examined with single-film technique. He found a high incidence of malignant lesions in his material and this finding has been a strong reason for remitting patients with dysphagia for radiologic examination.

Cineradiographic studies on the incidence of cricopharyngeal dysfunction have been published by Crichlow (1956) and by Seaman (1966). Other authors have studied the incidence of esophageal webs with the aid of cineradiography (Miller and Lewis 1963; Elwood et al. 1964; Blendis and Kreel 1965; Clements et al. 1974; Noshier et al. 1975). However, no more comprehensive study of the act of swallowing in patients with dysphagia and with the aim of reporting all functional disturbances observed in the pharynx and pharyngoesophageal junction seems to have been published.

The aim of the present investigation was to evaluate to what extent cineradiography of the swallowing act could contribute to a proper functional radiographic diagnosis among patients with dysphagia.

A very large number of the patients (80 %) in this series showed an abnormal cineradiographic pattern in the act of swallowing. The vast majority of the abnormalities were functional and only a few morphological lesions were revealed as, for instance, 5 Zenker-type diverticula in the posterior wall of the pharyngo-esophageal junction.

No patient was found to have an unknown malignant lesion in the pharynx or in the cervical portion of the esophagus. One patient had a squamous cell carcinoma in the right piriform sinus diagnosed on pharyngoscopy prior to the x-ray examination. A few patients had earlier been treated with radiotherapy for various kinds of malignancies in the neck region. This observation is contradictory to Macmillan's report in which 10 percent of the patients suffered from malignant lesions, excluding patients with foreign bodies (1931). The difference between the figures presented here and Macmillan's is astonishing as Macmillan stressed that his patients represented a "cross section of esophageal diseases". The only possible explanation is that the selection of patients has been completely different in Macmillan's investigation than in the present study.

To be valid, cineradiographic findings as those submitted in this report on patients with dysphagia must be compared with findings obtained from individuals without symptoms of dysphagia examined with a corresponding technique. The diagnostic differentiation between normal and abnormal patterns of swallowing was in the present study based on the results of an earlier performed investigation of 150 volunteers without swallowing complaints (Ekberg and Nylander). This report on cineradiography of the act of swallowing among normal volunteers performed at the same hospital and with an identical radiographic technique as in the present investigation offered such an opportunity.

Prior to this study pharyngeal constrictor paresis has been reported in patients with different kinds of generalized disorders like myasthenia gravis, amyotrophic lateral sclerosis, polymyelitis and also miscellaneous diseases in the brain stem

(Bosma 1953; Murray 1958, 1962; Silbiger et al. 1968). In the present investigation cineradiography could profitably contribute to the explanation of the patients' complaints. In our series the high incidence of pharyngeal constrictor paresis was rather astonishing. Only 6 patients had a complete palsy with abolished constrictor activity in all three portions of the pharyngeal constrictor musculature. In 19 patients the paresis was circumscribed and defined to one portion of the constrictors.

Only few reports have appeared earlier in the literature about circumscribed pharyngeal constrictor paresis (Ardran et al. 1957; O'Connor and Ardran 1976).

The present investigation has shown that these circumscribed pharyngeal constrictor pareses most probably would have been overlooked without cineradiography. Neither would a careful fluoroscopic examination in connection with a conventional single-film examination have disclosed the true nature of the disease. Due to their swallowing complaints these patients are often difficult to examine. This means that they have great difficulties in performing repeated large bolus swallowing which would be necessary for a proper fluoroscopic diagnosis.

Contrast medium entrance into the laryngeal vestibule and also further down to the rima glottidis and the trachea during deglutition has by some authors been regarded as a normal feature in the swallowing act (Ardran and Kemp 1951; Ramsey et al. 1955; Roberts 1957; Bachman 1959). However, this evidently erraneous suggestion seems to have been established on observations in individuals who probably suffered from swallowing difficulties and dysfunctions. The individuals have evidently been examined due to dysphagia.

According to the results of the present investigation dysphagial patients showed contrast medium entrance into the laryngeal vestibule in not less than 41 percent. If this figure is compared to that obtained in normal volunteers contrast medium entrance into the vestibule must be regarded as a suggestive sign of dysfunction. Under normal conditions contrast

medium enters the vestibule in only 5 percent of non-dysphagial volunteers and then only to a minor degree and into the uppermost portion of the vestibule, the subepiglottic portion (Ekberg and Nylander).

This discrepancy between dysphagial and non-dysphagial individuals strongly suggests that contrast medium entrance into the laryngeal vestibule is an abnormal occurrence. At least, if contrast medium entrance into the laryngeal vestibule below the subepiglottic level is taken into account, 16 percent of the patients with dysphagia showed this phenomenon that never appeared among the normal volunteers.

The epiglottis is normally tilted down during deglutition. (Ekberg and Nylander). In the present investigation abnormalities in the tilting down of the epiglottis was a common finding. The normal function of the epiglottis was not fully understood for a long time. In 1816 Magendie suggested that the epiglottis during swallowing protected the laryngeal aperture by tilting down. This was denied by several later authors as observations made on patients with traumatic or surgically excised epiglottic lips had shown that a "normal" swallowing was possible without the presence of this structure (Anderson 1891/92; Anderson Stuart and M'Cormick 1891/92; Negus 1927; Barclay 1930). However, later on Cannon and Moser (1898), who used radiofluorography, were able to examine individuals under more physiologic conditions. They stated that the epiglottis evidently tilted down to cover the laryngeal inlet during deglutition. This mechanism was later confirmed in other studies (Saunders et al. 1951; Rushmer and Hendron 1951; Ardran and Kemp 1951, 1952; Ramsay et al. 1955). Welin (1939) and Jonstone (1942) verified, the observation of Cannon and Moser (1898) that the epiglottis had the function to protect the superior laryngeal aperture and the laryngeal vestibule by a tilting down with its tip into the esophageal inlet.

The first account of epiglottic dysmotility was published by Welin who in 1939 reported on 5 patients with dysphagia with a slow return of the epiglottis from its inverted to its upright

resting position after swallowing. The results of the present investigation show that epiglottic dysmotility often occurs together with other aberrations from a symmetric and normal pattern of swallowing. In this series epiglottic obliquity was registered in 11 patients (4%). In 6 of these patients there were concomitant abnormalities. The same frequency of epiglottic obliquity has been observed among non-dysphagial volunteers. However, in none of these there were any concomitant abnormalities (Ekberg and Nylander).

Cricopharyngeal achalasia, subsequently referred to as cricopharyngeal dysfunction, has for a long time been recognized to cause dysphagia (Macmillan 1931; Asherson 1950; Crichlow 1956). Macmillan, using conventional x-ray technique, performed in 1931 an investigation of 921 patients with dysphagia and reported only 13 (1.5 %) instances of cricopharyngeal dysfunction. Crichlow in his classical description from 1956 reported that 62 percent of his patients subjected to cineradiography had a cricopharyngeal dysfunction. His diagnostic criteria seem to have been rather wide and he stated "...there is no normal radiologic picture of the cricopharyngeus because the cricopharyngeus is never visualized if the esophagus is acting normally". The diagnostic criteria of cricopharyngeal dysfunction used in the present investigation have been stricter than Crichlow's. This may explain the difference in incidence of cricopharyngeal dysfunction reported by Crichlow and that obtained in the present investigation. Crichlow's patients suffered from dysphagia but he makes no other remarks on cineradiographic abnormalities observed in the swallowing act other than the cricopharyngeal dysfunction.

The clinical significance of webs located in the postcricoid region of the esophagus has been the subject of much controversy. Some authors have claimed the insignificance of these webs (Seaman 1967; Clements et al. 1974; Noshier et al. 1975). Others have claimed that these webs can cause dysphagia (Mosher 1927; Macmillan 1931; Waldman and Turnball 1957). In the present investigation webs were found among 15 percent of the patients

which is in accordance with a recently published series of patients examined due to globus sensation among whom webs were found in 17 percent (Tada et al. 1979).

Zenker diverticula were found in 5 patients (2 %). This frequency is in accordance with Macmillan (1931) who found about 3 percent in his series. These pouches are probably seldom overlooked even on the single-films. However, the differentiation between small Zenker pouches and so called pseudodiverticula may be difficult without cineradiography. The true diverticulum enlarges when the pressure in the pharynx rises on the passage of the bolus. A pseudodiverticulum is on the contrary effaced during the same conditions as it is dependent only on the in-bulging of the cricopharyngeal muscle which at the peak of the deglutition usually relaxes.

An important observation in the present investigation is the high frequency with which concomitant aberrations in the act of swallowing is revealed by cineradiography (Table 3). This is in contrast to non-dysphagial individuals in whom we found concomitant abnormalities in only 2 of 26 patients (Ekberg and Nylander). This means that dysphagial patients have regularly more severe and frequently more than one aberration.

The results of the present investigation have made it clear that a properly performed cineradiography of the act of swallowing is a profitable radiographic method to be used in the routine examination of patients with dysphagia. The results indicate that 80 percent of the patients with dysphagia have underlying functional disturbances in the act of swallowing that can be discovered by the aid of cineradiography. Most of these aberrations were not disclosed by the single-film technique. In view of this fact the patients' complaints could not have been explained without cineradiography.

ABSTRACT

In order to define the diagnostic outcome of cineradiographic examination of the swallowing act (pharyngeal stage) in patients with dysphagia 250 such patients were consecutively examined with a filmspeed of 50 and 100 frames per second. Synchronous and symmetric swallowing was observed in 20 percent of the patients while 80 percent of the patients exhibited functional abnormalities, i.e., epiglottic dysfunction (33 %), misdirected swallowing and aspiration (41 %), cricopharyngeal dysfunction (22 %), paresis of the pharyngeal constrictor musculature (10 %), webs (15 %) and Zenker diverticula (2 %). These results clearly indicate that cineradiography frequently can disclose functional abnormalities in the act of swallowing among patients with dysphagia and explain the complaints of these patients. Cineradiography is clearly superior to conventional single film technique in revealing functional abnormalities in the act of swallowing.

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PHARYNGEAL CONSTRUCTOR PARESIS IN PATIENTS WITH
DYSPHAGIA

A cineradiographic study

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The radiographic pattern of pharyngeal paresis is multifarious and includes a wide variety of aberrations from a complete inability to swallow to minor disturbances in the act of swallowing. Patients with complaints of dysphagia will often be subjected to a routine pharyngeal x-ray examination. Such examinations are well-suited to reveal morphological pharyngeal changes, but are less appropriate to demonstrate functional disturbances in the act of swallowing. Patients with dysphagia who are referred to the X-ray Department of Malmö General Hospital are therefore in addition to the routine examination always subjected to a cineradiography of pharyngeal deglutition.

In a recently performed review of dysphagial patients no less than 80 percent of them showed functional aberrations in the act of swallowing. In about 10 percent of the patients the cineradiograms showed a pharyngeal constrictor paresis involving varying portions of the muscle (1). The purpose of this report was to describe the cineradiographic pattern of circumscribed paresis of the pharyngeal constrictor musculature among patients with dysphagia.

Material and Methods

The material was obtained from a group of 250 patients consecutively subjected to cineradiography of pharyngeal deglutition due to dysphagia. A review of these patients revealed 25 with a more or less pronounced paresis of the pharyngeal constrictor musculature.

The material proper thus consisted of 25 patients, 16 males and 9 females, aged between 45 and 93 years (mean 72 years) who prior to cineradiography had been subjected to a thorough routine x-ray examination. This comprised fluoroscopy, plain films in different projections before and after barium swallowing as well as films taken during barium swallowing.

The cineradiograms were performed with the aid of a Camêmatic GV 16 Super camera connected to an x-ray image intensifier and a cine-pulse unit. Exposures were made at 80 kV, 125 mA and with an

exposure time for each frame of 1-5 ms. Films were obtained with a speed of 50 and 100 frames per second. Every cineradiographic examination comprised two AP and two lateral series.

To obtain an optimal recording of the act of swallowing the patients were instructed to swallow a large mouthful of a barium contrast suspension (60 %, w/w). After this initial barium swallow the patients were asked to perform repeated acts of secondary swallowings in order to demonstrate their capacity to clear the pharynx of contrast medium.

The obtained cineradiograms were analyzed with the aid of a cine-film analector (Steenbeck ST 1100) and scrutinized for aberrant patterns in the act of swallowing.

The motor activity of the pharyngeal constrictor musculature was studied frame by frame as the peristaltic stripping wave passed down the pharynx to the esophagus. Interruption of the normal propulsive pharyngeal peristalsis was interpreted as a regional paresis of the pharyngeal constrictor musculature. Contrast medium retention in the valeculae and in the piriform fossae after repeated attempts to clear the pharynx of contrast medium was regarded as an indirect sign of insufficient pharyngeal constrictor activity. Contrast medium entrance into the laryngeal vestibule was registered and also aspiration of retained contrast medium from the pharynx. An indentation in the posterior and upper aspect of the esophagus corresponding to the position of the cricopharyngeal muscle was interpreted as a dysfunction of cricopharyngeal relaxation.

Results

A summary of the results is given in Tables I and II. From the tables it is clear that 6 patients showed an almost complete paresis of the pharyngeal constrictor musculature (Fig. 1). In 16 patients a circumscribed paresis of the middle pharyngeal constrictor was demonstrated, while the superior and inferior constrictors showed normal peristaltic activity (Fig. 2). In two patients a paresis of the middle and inferior pharyngeal con-

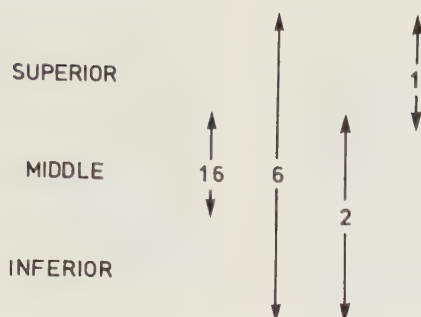


Table I

Extension of the lesion in the pharyngeal constrictor musculature in 25 patients with paresis.

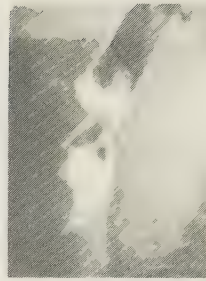
Concomitant cine-radiographic examination findings	Portion of constrictor and number of patients			
	Superior	Superior	Middle	Inferior
	Middle			Middle
	Inferior			
	6	1	16	2
Immobile epiglottis	4		6	1
Impairment of the second movement of the epiglottis	2	1	10	1
Indentation due to cricopharyngeal muscle	2		6	
Misdirected swallowing	6	1	14	2
Retention of contrast medium in the pharynx after the first swallowing	6		13	2
Retention after repeated swallowing	5		2	1

Table II

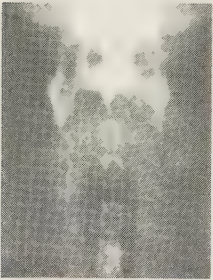
Extension of the paresis in the pharyngeal constrictor musculature and concomitant cineradiographic findings.



a



f



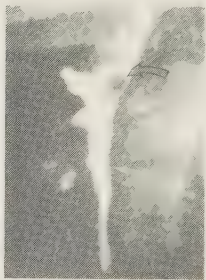
b



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c



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d



i

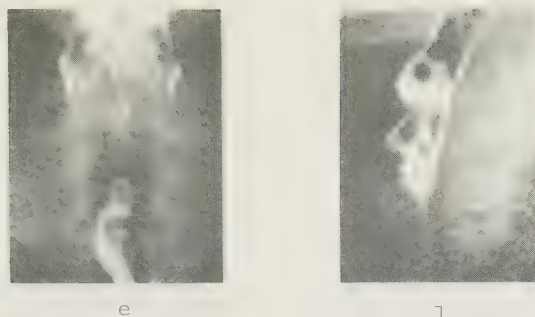


Fig. 1. Sequence from a cineradiographic examination (a-e) AP projection, (f-j) lateral projection. There is no contraction in the pharyngeal constrictors (thin arrows). The epiglottis (open arrow) is immobile. Contrast medium enters into the vestibule (bent arrow) and the trachea.

strictors was observed and in one individual a circumscribed paresis of the superior pharyngeal constrictor could be demonstrated.

It is also clear from Table II that the observed instances of partial pharyngeal paresis invariably appeared together with other functional disturbances. The epiglottis remained completely immobile during the act of swallowing in 11 patients (44 %) (Fig. 1). In the remaining 14 patients its motility was restricted to the first part of the swallowing movement while the final tilting down of its tip into the esophagus failed to appear. A misdirected swallowing with contrast medium entrance into the laryngeal vestibule was observed in 23 patients (Figs 1 and 2). A dysfunction of the cricopharyngeal muscle was observed in 8 patients (Fig. 2).



Fig. 2. Sequence from a cineradiographic examination. Lateral projection. There is defective function in the middle constrictor musculature (thin arrow), while some activity is seen in the superior and inferior constrictors (thick arrows). There is entrance of contrast medium into the vestibule (bent arrow). The cricopharyngeal muscle does not relax properly (open arrow).

Discussion

The diagnostic value of cineradiography in the examination of patients with pharyngeal paresis was first stressed by Ardran and Kemp in 1956 (2). They proposed that every patient with unexplained swallowing complaints should be subjected to a cineradiographic examination of pharyngeal deglutition even if the patient's routine pharyngeal examination appeared quite normal. They have described absence of motility or weakness of the pharyngeal constrictors as due to partial paresis after poliomyelitis (3). In 1956 Ardran and Kemp (2) reported a patient with circumscribed paresis of the middle pharyngeal constrictor. They ascribed it to be sequential to a trauma to the neck. In 1964 Lund and Ardran (4) reported on 6 patients with circumscribed pharyngeal paresis in the upper or middle portion of the constrictor.

Bosma (5) studied , by radiography, swallowing dysfunction secondary to poliomyelitis and drew the conclusion that isolated paresis in the pharynx is without pathological significance. A similar statement was made earlier by Kronecker and Meltzler (6) referring to experiments on cats which had had the pharyngeal constrictor muscle divided without any obvious impairment of the swallowing act. Contrary to this, the present investigation reports a high frequency of circumscribed pharyngeal paresis in patients referred to x-ray examination for dysphagia.

The cortical motor center of the larynx and the pharynx is to be found at the lowest part of the precentral convolution. The axons of the cortical cells pass, as the corticobulbar tractus via the corona radiata, the internal capsule and the cerebral peduncle to the nucleus ambiguus of the medulla (7, 8, 9, 10). The fibers from the cortical centers travel mainly to the contralateral side of the medulla but also to the ipsilateral nucleus ambiguus (11). This form of bilateral innervation is the general arrangement for the cranial motor nerves supplying the tongue, the jaw musculature, the larynx and the pharynx. Nucleus ambiguus is the motor center for the glossopharyngeal, cervical vagus and accessorius cranial nerves. It is located in the lateral aspect of the medulla oblongata in the floor of the fourth ventricle and

it has a considerable extension in the longitudinal direction of the medulla.

The glossopharyngeal nerve derives its axons from the rostral end of the nucleus ambiguus, the cervical vagus from the rostral and intermediate portions while the accessorius nerve derives its axons from the caudal portion of the nucleus. It is indeed difficult to identify any strict borderlines between the nuclei of the IXth, Xth and XIth cranial nerves. Furthermore, the fibers of these nerves merge to form the so-called pharyngeal plexus encircling the constrictor musculature of the pharynx (9).

The constrictor musculature of the pharynx is composed of three portions, i.e., the superior, middle and inferior. The superior portion of the constrictor is attached to different structures on the base of the skull and also emerges from the transverse musculature of the tongue. The middle constrictor is attached to the hyoid bone and the stylohyoid ligament. The inferior constrictor emerges from the thyroid and cricoid cartilages. The muscles from each side unite posteriorly into the pharyngeal raphe. The muscles function as a unit with a propulsive peristalsis that normally passes through the pharynx without any interruption.

Due to the described arrangement of the nerve supply with a substantial "overlapping" of the nerves within the pharyngeal plexus a total paresis is very rarely, if ever, caused by a vascular lesion. A total pharyngeal palsy is the result of a widespread lesion involving the whole extension of the nucleus ambiguus or a myogenic disease. Consequently total pharyngeal palsy is a rare entity that is met with only in severely disabling conditions, such as bulbar poliomyelitis, syringobulbia, amyotrophic lateral sclerosis, disseminated sclerosis and myasthenia gravis (12, 13, 14, 15). Contrary to this, circumscribed pharyngeal paresis seems to be a fairly common phenomenon encountered in about 8 percent of the patients referred to radiologic examination of the pharynx due to dysphagial complaints (1).

A comparison between the diagnostic information obtained from routine pharyngeal x-ray examination and the cineradiograms revealed that none of the 19 cases with circumscribed pharyngeal

constrictor paresis could have been detected without a properly performed cineradiography. From this observation it is evident that a cineradiographic examination of pharyngeal deglutition is essential for diagnosing circumscribed pharyngeal constrictor paresis.

The importance of radiology in the diagnosis of pharyngeal palsy has long been known (2, 3, 5, 13, 16). In the early radiologic era the diagnosis was based mainly on fluoroscopic observations. The diagnosis was also based on indirect signs like retention of contrast medium in the gullet. It is true that the examiner can obtain valuable information about the functional state of the pharynx by a skilled fluoroscopy of the pharyngeal stage of deglutition. However, even in experienced hands the examination is time-consuming and difficult as only a minor detail in the act of swallowing can be scrutinized for every swallowing. This means that the patients have to swallow large amounts of contrast medium. This is a minor problem in healthy individuals. However, in disabled patients, especially those with misdirected swallowing, the procedure can be troublesome (17). The examination may even be hazardous if barium suspension enters the airways. Under normal conditions the act of swallowing includes a sequence of fairly rapid events. The apex of the bolus passes from the pharyngeal fauces to the cervical esophagus in about one third of a second. This makes fluoroscopy difficult, especially in patients with malfunctions in the act of swallowing. These patients have a tendency to compensate for their inability by turning the head and moving the trunk in order to involve secondary and accessory swallowing muscles. For this reason smaller aberrations like a circumscribed pharyngeal constrictor paresis are almost impossible to diagnose with any degree of certainty by fluoroscopy and single-film exposures. With the introduction of cineradiography the radiologic diagnosis is enhanced and much of the above described inconveniences can be overcome.

From the results of the present investigation it is clear that the cineradiographies in all patients showed besides the pharyngeal paresis invariably one or several concomitant aberrations in the act of swallowing. In Table II it is seen that all patients

had an impaired motility of the epiglottis. Fourteen patients had a normal first movement, a tilting of the epiglottis to the transversal position, while in all patients the final tilting of the epiglottis down into the esophageal inlet failed to appear. A misdirected swallowing, where a varying amount of contrast medium entered the laryngeal vestibule and sometimes also was seen as far down as in the subglottic region, was very common. An indentation due to the cricopharyngeal muscle was observed in 8 patients and this was regarded as indicating a cricopharyngeal dysfunction. Retention of contrast medium in the gullet immediately after the initial swallowing was observed in 21 patients, while 8 of these still had retention after several (more than three) secondary swallowings. None of these concomitant aberrations were seen more frequently together with any special type of pharyngeal constrictor paresis.

The diagnosis of pharyngeal paresis cannot with any degree of certainty be based on indirect signs like retention of contrast medium. The only accurate method for this diagnosis is the visualization of the restricted movement of the pharyngeal wall, which is a direct and reliable sign of the paresis.

The subjective complaints of dysphagia due to functional abnormalities can be rather transient either due to recovery but probably more frequently due to compensation (3, 18). This means that it is possible for the patient to compensate for an inadequate pharyngeal constrictor function by a vigorous chewing of the food, by rinsing the pharynx with a lot of fluid together with a solid bolus, but also by synchronous movements of the head and neck whereby accessory swallowing muscles can more powerfully be utilized (3, 5).

ABSTRACT

Among 250 patients examined by cineradiography because of dysphagia 25 were found to have a more or less pronounced paresis of the pharyngeal constrictor musculature. The paresis included all three portions of the muscle in 6 patients. A circumscribed lesion was found in 19 patients and included the superior portion of the pharyngeal constrictor muscle in 1 patient, the middle portion in 16 patients and the middle and inferior portions in 2 patients. All 25 patients exhibited concomitant cineradiographic abnormalities. i.e., impairment of the tilting down of the epiglottis, dysfunction of the cricopharyngeal muscle and retention of contrast medium in the pharynx. With the aid of cineradiography it is possible to disclose an underlying pharyngeal constrictor paresis in about 10 percent of patients with dysphagia who are referred for radiographic examination. In most patients suffering from a circumscribed pharyngeal paresis the diagnosis will be overlooked in a routine examination, on the other hand it is easily disclosed at cineradiography.

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DYSFUNCTION OF THE CRICOPHARYNGEAL MUSCLE
A cineradiographic Study in Patients with Dysphagia

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Functional disturbances of the cricopharyngeal muscle with an inability to relax in a proper way during swallowing have long been recognized as one of many possible causes of dysphagia. The patients' complaints may vary from a slight and obscure sensation of a lump in the throat to the most severe swallowing difficulties (1, 2, 3). A cricopharyngeal dysfunction - an incoordinated relaxation or a disability to a proper relaxation of the muscle - is in the literature often referred to as cricopharyngeal achalasia. As this expression is appropriate only for a complete inability of the muscle to relax it is avoided in this report. The purpose of the present investigation was to study how often and to what extent a disturbed relaxation of the cricopharyngeal muscle appeared in patients with dysphagia on routine examinations and on cineradiography.

Material and Methods

The material was obtained from 250 patients consecutively referred to x-ray examination of the pharynx and esophagus due to dysphagia. All the patients were subjected to a routine x-ray examination followed by a cineradiography of pharyngeal deglutition.

The routine x-ray examination comprised plain films and films obtained during and after barium swallowing. The plain films and the films during barium swallowing were obtained in the PA and left lateral projections. The films after barium swallowing were taken in lateral, PA and LAO and RAO projections.

The cineradiograms were obtained with the aid of a cine-pulse unit and a Camêmatic GV Super 16 mm film camera mounted on a 9 inch x-ray image intensifier. A total of at least four primary swallowings of a mouthful of barium contrast medium (60 % w/w) and several secondary swallowings were obtained with a speed of 50 or 100 frames per second. The cinefilms were analyzed with a Steenbeck analector utilizing a frame by frame technique.

Dysfunction of the cricopharyngeal muscle was defined as follows. At the moment when the cervical portion of the esophagus down to the level of the seventh cervical vertebral body was distended by the bolus as seen in the lateral projection, an indentation in the posterior wall of the pharyngo-esophageal junction due to the cricopharyngeal muscle was registered as dysfunction (Fig. 1). The depth of this indentation was arbitrarily used to classify the indentations into three degrees: 1) indentations less than one fourth, 2) less than half and 3) more than half of the diameter of the adjacent esophagus (Fig. 2).



Fig. 1. An indentation in the posterior wall of the pharyngo-esophageal junction due to the cricopharyngeal muscle (arrow). The cervical portion of the esophagus is well distended by the bolus (open arrow).

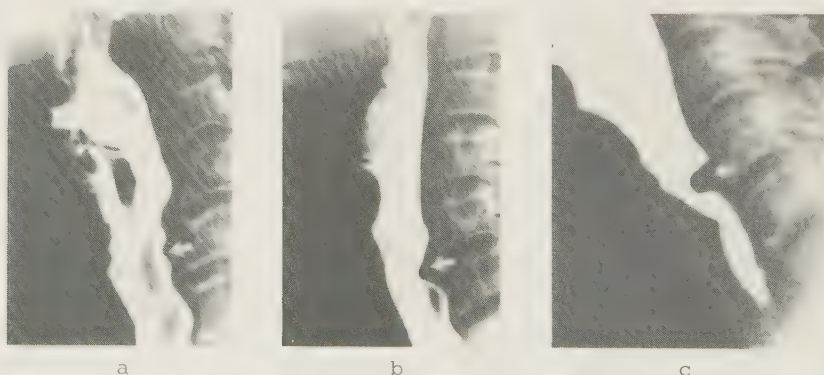


Fig. 2. The depth of the indentation (arrow) of the cricopharyngeal muscle in the posterior wall of the pharyngo-esophageal junction according to the used classification in three degrees. a) an indentation with a depth less than one fourth of the sagittal diameter of the adjacent esophagus (first degree), b) between one fourth and half (second degree), c) more than half (third degree).

The further behavior of the cricopharyngeal indentation during the passage of the bolus was also studied, i.e., whether it remained unchanged (continuous type) or disappeared (transient type) during the passage of the bolus (Figs 3, 4).

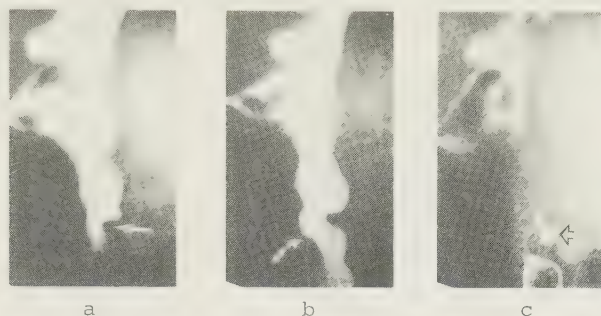


Fig. 3. Sequence of a cineradiography in a patient with cricopharyngeal dysfunction causing an indentation (arrow) in the posterior wall of the hypopharynx throughout the swallowing act. At the end of the swallowing act (c) contrast medium is retained cranial to the cricopharyngeus (open arrow). In a) and b) it is clearly seen that no true diverticulum is present. There is a web in the upper cervical esophagus (bent arrow).

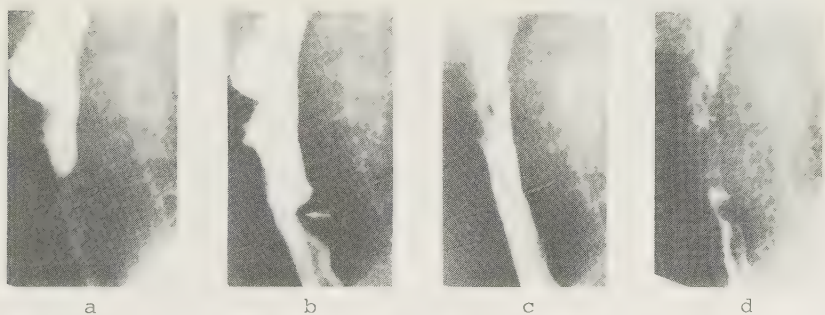


Fig. 4. Sequence of a cineradiography of the hypopharynx. The indentation (arrow) of the cricopharyngeal muscle is seen only during the early stage of the swallowing act in a) and b).

The cineradiograms were scrutinized with regard to other dysfunctions, i.e., pharyngeal constrictor paresis, epiglottic dysmotility, contrast medium entrance into the laryngeal vestibule, retention of contrast medium above the cricopharyngeal indentation and the appearance of esophageal webs. Special attention was also paid to the posterior wall of the hypopharynx immediately cranial to the transverse portion of the cricopharyngeal muscle, i.e., the small triangular area bounded by the transverse and oblique portions of this muscle. In patients with cricopharyngeal dysfunction a certain amount of contrast medium often remains in this region after swallowing. This phenomenon is subsequently referred to as a pseudodiverticulum (Fig. 5). This entity can be defined as an occasional recess formation in the lowermost portion of the hypopharynx. It is formed during the act of swallowing at the cranial aspect of the cricopharyngeal indentation.

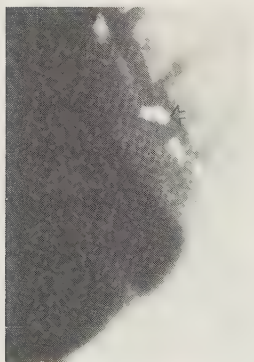


Fig. 5. Lateral view of hypopharynx immediately after the barium bolus has passed. There is retention of contrast medium in the area of the pharyngo-esophageal junction (open arrow). No distinction can be made between a Zenker diverticulum and contrast medium retention due to an indentation of the cricopharyngeal muscle on this single-film.

The diagnostic information obtained about the function of the cricopharyngeal muscle from conventional examinations was compared to that obtained from the cineradiographies.

Results.

Cineradiography revealed that 55 (22 %) of the 250 patients with dysphagia exhibited a cricopharyngeal indentation. The material proper thus comprised 23 males and 32 females aged between 35 and 93 years (mean 65 years). With conventional examination it was possible to diagnose the cricopharyngeal indentation in 22 of the 55 patients (40 %).

The number of registered concomitant abnormalities and their relation to the three different degrees of cricopharyngeal indentations in the esophagus are given in Table I. From this table it is clear that 35 patients besides the cricopharyngeal indentation showed one, two or several concomitant abnormalities in the act of swallowing. The remaining 20 patients exhibited cricopharyngeal dysfunction as the only cineradiographic finding.

Table I

Number of patients with and without concomitant cineradiographic abnormalities in the act of swallowing according to degree and type of cricopharyngeal indentation.

TYPE OF CONCOMITANT CINERADIOGRAPHIC FINDINGS	1st degree		2nd degree		3rd degree	Nos
	transient type	continuous type	transient type	continuous type	continuous	
Pharyngeal constrictor paresis	1	2	1		4	8
Epiglottic dysfunction	4	4	2	1	6	17
Misdirected swallowing	6	3	7	2	5	23
Web	4	3	5	2	5	19
Zenker diverticulum			1			1
Pseudodiverticulum	4	3	2		4	13
No concomitant cineradiographic findings	7	2	7	2	2	20

25 2

A pseudodiverticulum-formation was observed cranial to the transverse portion of the cricopharyngeal muscle in 13 patients (Fig. 5). A web formation was registered in the uppermost ventral aspect of the esophageal wall in 19 patients. An epiglottic dysfunction was observed in 17 patients, i.e., the epiglottis was not tilted down in a proper way during the act of swallowing. A misdirected swallowing was noticed in 23 patients. Partial pharyngeal constrictor paresis was observed in 8 patients.

Of the 55 patients with cricopharyngeal dysfunction the cricopharyngeal indentation was transient in 36, i.e., it was seen during the early phase of swallowing but disappeared during the late phase (Fig. 4). In the remaining 19 patients the indentation was sustained during the whole act of swallowing (Fig. 3).

A first degree cricopharyngeal indentation was observed in 29 patients, a second degree in 18 patients and a third degree in 8 patients (Fig. 2).

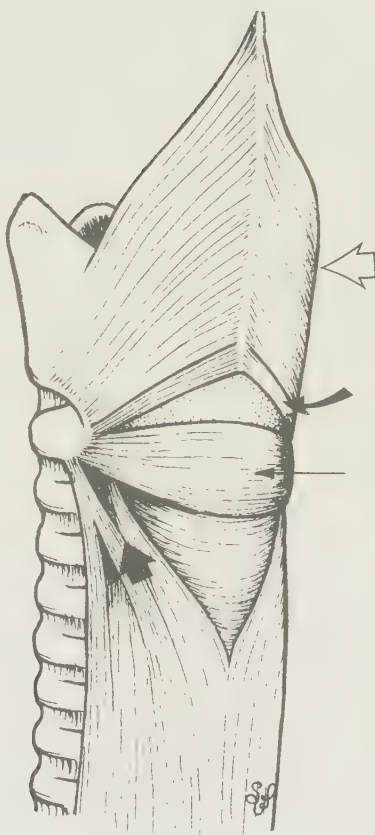
Of the 29 indentations of the first degree 21 were of the transient type and 8 of the continuous type. The corresponding figures for indentations of the second degree were 15 and 3, respectively, while all the cricopharyngeal indentations of the third degree were of the continuous type. A brief summary of the results is given in Table I.

Discussion

Anatomically the cricopharyngeal muscle, the superior esophageal sphincter, can be distinguished into three portions, all of which are fairly well defined (Fig. 6). The superior portion of the muscle is called pars obliqua and is found in close connection with the inferior pharyngeal constrictor. Its muscle bundles emerge from the lateral aspects of the cricoid cartilage and project in an oblique craniodorsal direction to join the muscle of the contralateral side in the raphe pharyngeus of the posterior wall of the hypopharynx. The middle portion of the cricopharyngeal muscle is attached to the posterior and lateral aspects of the cricoid cartilage from which it surrounds the esophagus in a semicircular way. It is separated from the pars

Fig. 6. Anatomical drawing of the pharyngo-esophageal junction with the three portions of the cricopharyngeal muscle seen from the left and behind. Pars obliqua (bent arrow), pars transversa (thin arrow) and pars longitudinalis (thick arrow). Inferior pharyngeal constrictor (open arrow).

(Drawing by
Sigurdur V. Sigurjónsson, M.D.)



obliqua by a triangular area of fibrous tissue. This area, the interspace between pars obliqua and pars transversa, has been called Killian's dehiscence or, less accurately, the Laimer triangle. This area is characterized by its scarcity of musculature. The inferior portion of the cricopharyngeal muscle, pars longitudinalis, is attached to the inferior aspect of the cricoid cartilage. The muscle bundles emerge downward and converge with the longitudinal muscle bundles of the esophagus. Their function seems to be to elevate the esophagus during deglutition. Further on, in this report the term 'cricopharyngeal muscle' is used to designate the transversal portion of the muscle.

During normal resting conditions the cricopharyngeal muscle is kept in a state of tonic contraction and serves as the upper esophageal sphincter. The tonic cricopharyngeal contraction prevents air from passing down from the pharynx to the esophagus on inspiration, and in patients with gastro-esophageal reflux the muscle acts as a barrier to prevent a further reflux of gastric content into the pharynx.

The motor nerve supply of the pharyngeal constrictors and the cricopharyngeal muscle is derived from the nucleus ambiguus (the somatic nucleus of the ninth, tenth and eleventh cranial nerves), from the dorsal motor nucleus of the vagus and from the cervical sympathetic via the uppermost cervical ganglion. Thus, the cricopharyngeal muscle may have a complex innervation from three different centers (4, 5, 6).

The tonic contraction of the cricopharyngeus is mediated by a sympathetic stimulation while relaxation of the muscle is affected by parasympathetic stimulation (2, 7). According to Kirchner and Sjöberg a relaxation of the cricopharyngeus would imply a cessation of sympathetic stimulation followed by a vagus-mediated relaxation.

The cricopharyngeal muscle begins to relax at the same moment as the pharyngeal constrictors start to contract, i.e., when the bolus enters the fauces pharyngis and before the bolus has reached the pharyngeal outlet at the level of the cricopharyngeus (4, 6). This suggests that pharyngeal contraction and cricopharyngeal relaxation are both initiated by one and the same trigger mechanism - a sensory pharyngeal stimulation.

From cineradiographic observations it is evident that the cricopharyngeal muscle has two principally different functions (10). The first one is the sphincteric function, which is well documented by manometric and radiographic studies. The other function has so far not been mentioned in the pertinent literature but is to participate in the coordinated and propulsive peristaltic contraction of the pharyngo-esophageal constrictors during deglutition. In cineradiography of normal individuals it is not possible to differentiate the cricopharyngeal muscle from the other constrictors during the act of swallowing. The cricophar-

yngeal muscle is recognized first after the bolus has passed and the other pharyngo-esophageal constrictors have relaxed and now only because it does not relax. On the contrary, it now remains in tonic contraction.

From the available data the swallowing mechanism seems to be as follows. The afferent sensory impulses evoking the reflex of deglutition are mediated via the fifth, ninth and tenth cranial nerves to the tractus solitarius and the nucleus solitarius and from here to a swallowing center in the substantia reticularis of the medulla. The swallowing center delivers inhibitory impulses to the cervical sympathetic ganglia by which the tone of the cricopharyngeal muscle is abolished. Simultaneously efferent impulses are sent from the swallowing center to the nucleus ambiguus and a pharyngeal propulsive contraction is started via impulses in the ninth, tenth and possibly also the eleventh cranial nerves. The peristalsis then travels down the pharynx and the pharyngo-esophageal junction where the cricopharyngeal muscle participates in this peristalsis. However, when the other muscular structures relax after the passage of the peristaltic wave the cricopharyngeal muscle maintains its contraction that corresponds to its normal resting condition (6).

The described sequence of events explains why the cricopharyngeal muscle is never seen as an indentation in the gullet of normal individuals during deglutition. This important observation was expressed by Crichlow in the following statement: "... there is no normal radiologic picture of the cricopharyngeus because the cricopharyngeus is never visualized if the esophagus is acting normally" (11).

The term 'cricopharyngeal achalasia' is often used in the literature to designate conditions where the relaxation of the cricopharyngeal muscle during swallowing is insufficient or delayed (12, 13). 'Achalasia' means "not relaxing" and therefore it seems inappropriate to use this expression for conditions where the muscle in reality relaxes, even if this relaxation is delayed or incomplete. Cricopharyngeal dysfunction seems to be a more adequate denomination for the conditions dealt with in this report (11).

The first radiologic investigation concerning the frequency of dysfunction of the upper esophageal sphincter was performed by MacMillan in 1931 (14). He found "acute spasm at the entrance to the esophagus" in 13 patients among 921 examined with conventional technique due to dysphagia.

Crichlow examined a group of patients with complaints of dysphagia with cineradiography and reported that 62 percent of them showed a cricopharyngeal indentation (11). The corresponding figure for the present investigation was 22 percent. However, Crichlow did not account for the selection of his material and his definition of cricopharyngeal dysfunction was wider than that used in this report.

Silbiger (15) examined 101 patients with different neuromuscular disorders and dysphagia with the aid of cineradiography. He found that 36 percent suffered from dysfunction of the upper esophageal sphincter. This figure is higher than that obtained in the present investigation (22 percent). This discrepancy may be explained by a different selection of patients included in his investigation and that of the present study. Neither of these is any true investigation of the real incidence of cricopharyngeal dysfunction.

Few reports have appeared concerning the frequency of cricopharyngeal indentation in individuals without swallowing complaints (16, 17). In a recent cineradiographic study of the act of swallowing of 150 non-dysphagial volunteers 5 percent were shown to have a demonstrable cricopharyngeal indentation (18). Seaman in 1966 made a similar cineradiographic study of 200 individuals without dysphagia and reported that 5 percent had such an indentation (17). These two reports make it clear that a transient cricopharyngeal indentation, suggesting a dysfunction, may be asymptomatic.

There was a considerable individual variation in the depth of the indentation of the muscle on the cineradiogram. The indentation also varied in one and the same patient from one swallowing to another. In many patients the indentation was only substantial during a very brief moment in the act of swallowing. This nonuniform appearance of the cricopharyngeal indentation

may explain why an ordinary X-ray examination so often fails to demonstrate the dysfunction. It may also explain the difference in incidence reported by various authors. In the present investigation only 22 of the 55 cineradiographically demonstrable cricopharyngeal indentations could be detected on a conventional x-ray examination. These observations strongly stress the necessity to include a cineradiography of the act of deglutition in the routine examination of patients with dysphagia.

The illusive radiographic appearance of the cricopharyngeal indent can be explained by the nonconformity of conditions under which the routine examinations are performed. In the present investigation the reproducibility of the cricopharyngeal indentation was obviously related to the size of the bolus. This means that a small bolus failed to distend the pharynx sufficiently to visualize the cricopharyngeal indentation.

Patients with dysphagia regularly change their habitual technique of deglutition to smaller and repeated swallows (12). This often obscures the cricopharyngeal indentation and makes the diagnosis so precarious. For this reason it is of the utmost importance to instruct the patients to take a large mouthful of contrast medium and to swallow it all at once.

As mentioned earlier, the cricopharyngeal indentation varied between different patients included in the present investigation. In some cases it was only transient, in others it remained unchanged during the whole act of swallowing. From Table I it is clear that 21 of the 29 cricopharyngeal indentations of the first degree were transient while all 8 indentations of the third degree were continuous. This observation suggests that cricopharyngeal dysfunction may appear in two forms. The first one is recognized as a delayed relaxation of the muscle. A shallow indentation in the esophagus is seen only during the first part of the act of swallowing. Later the muscle is fully relaxed and its indentation consequently disappears (Fig. 4). The other form of cricopharyngeal dysfunction is recognized as an inability of the muscle to complete relaxation. It is distinguished by a shallow or deep esophageal indentation that remains present during the whole act of swallowing (Fig. 3).

No correlation has been made in the present investigation between the degree of dysphagia and the appearance of the cricopharyngeal indentation. However, concomitant pharyngeal constrictor palsy was more frequent among patients with the continuous type of cricopharyngeal indentation. These patients also showed misdirected swallowing more often than the others. This circumstance may indicate that the continuous type of cricopharyngeal indentation is a more severe form than the transient type. Retention of contrast medium cranial to the cricopharyngeal muscle indentation was seen only in patients with concomitant pharyngeal constrictor palsy. That means that even a large indentation when isolated does not result in retention probably because the patients are swallowing a small bolus. This has been reported also by Murray (12) and Bosma (16).

It is difficult to differentiate an indentation due to the cricopharyngeal muscle and one caused by a cervical osteophyte on a single-film. On cineradiography the differentiation is much easier as the cricopharyngeal indentation follows the movement of the esophagus during swallowing.

The histopathological appearance of the muscle in patients with cricopharyngeal dysfunction has been studied by several authors (3, 8, 16, 19, 20, 21, 22). The muscle has in these patients been claimed to be normal or subjected to fibrosis, hypertrophy or hyperplasia.

Such a distinction is radiographically impossible. Cineradiography can only offer possibilities for studying the form and the behavior of the cricopharyngeal muscle during swallowing.

Figure 5 illustrates a lateral view of the hypopharynx after a barium meal. It is often very difficult and sometimes impossible to decide whether the pouch formed in the posterior aspect of the pharyngo-esophageal junction represents a pseudodiverticulum formed by a cricopharyngeal indentation or whether it represents a true diverticulum. A cineradiography gives a proper differential diagnosis without any risk of misinterpretation (Fig. 3). A true Zenker diverticulum and a pseudodiverticulum behave differently on the passage of a contrast medium bolus. A Zenker diverticulum

dilates as the intraluminal pressure of the gullet is raised on the passage of a contrast medium bolus. A pseudodiverticulum disappears under the corresponding conditions.

It has been discussed in the literature whether this form of pseudodiverticulum formation may precede the formation of a true diverticulum (9, 17, 23 - 27). No author has been able to demonstrate a transition from a pseudodiverticulum to a true Zenker diverticulum. The present study gives no information about this problem. However, pseudodiverticula were common in the presented material where only one Zenker diverticulum was registered. This may suggest that a pseudodiverticulum by no means can be looked upon as a precursor of a real diverticulum formation. This means that the presence of a pseudodiverticulum only reflects a dysfunction of the cricopharyngeal muscle. In the present investigation no pseudodiverticulum was seen without a concomitant dysfunction of the cricopharyngeal muscle.

From Table I it is clear that a cricopharyngeal indentation very often appears together with other forms of dysfunction in the act of swallowing among patients with dysphagia, i.e., dysfunction of the epiglottis - an aberrant pattern of movement during swallowing, misdirected swallowing and pharyngeal constrictor paresis. When cricopharyngeal dysfunction is present in individuals without dysphagia it appears as a solitary phenomenon (18). In the present investigation of patients with dysphagia it appeared together with other dysfunctions in not less than 68 percent of the patients. This suggests that these patients suffer from a neuromuscular disorder in which the cricopharyngeal dysfunction is only one aspect.

ABSTRACT

In a consecutive series of cineradiograms performed in 250 patients with dysphagial complaints 55 were found to suffer from a dysfunction of the cricopharyngeal muscle (achalasia). The diagnosis was based on the finding of an indentation of the muscle in the pharyngo-esophageal junction during swallowing. It measured less than one fourth of the esophageal diameter in 29

patients, less than half of the esophageal diameter in 18 patients and more than half of the esophageal diameter in 8 patients. The indentation was either transient (36 patients) or continuous (19 patients). In 35 of the patients concomitant aberrations in the swallowing act were revealed, i.a., pharyngeal constrictor paresis (8 patients), epiglottic dysfunction (17 patients), mis-directed swallowing (23 patients) and esophageal webs (19 patients). This study indicates that a cricopharyngeal dysfunction is present in 22 per cent of patients referred to x-ray examination due to dysphagia and that it often is accompanied by other deglutitional aberrations. Cineradiography of the swallowing act is of the utmost importance in the diagnosis of cricopharyngeal dysfunction; a diagnosis that very often will be overlooked in a routine examination.

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THE MOVEMENT OF THE EPIGLOTTIS DURING DEGLUTITION

A Cineradiographic Study

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The protection of the larynx during the act of swallowing is essential to prevent aspiration. The entrance to the airway is therefore during the act of swallowing closed by three different mechanisms: an obturation of the rima glottidis, a closure of the laryngeal vestibule and finally by a tilting down of the epiglottis to cover the laryngeal inlet.

The mechanism by which the movement of the epiglottis is accomplished has been the subject of much controversy. An attractive and ingenious theory to explain the swallowing movements of the epiglottis has been proposed (1, 2, 3). However, our understanding of this complex mechanism is still incomplete and deserves further interest. The purpose of this investigation was to study the movements of the epiglottis with the aid of a high speed cineradiographic technique in an attempt to elucidate the mechanism behind its tilting down during swallowing.

Material and Methods

The material consisted of 150 cineradiographies of the swallowing act obtained from the same number of volunteers (79 male and 71 females). These were aged 20 - 82 years with a mean age of 52 years. The volunteers were recruited from patients remitted to the X-ray Department of Malmö General Hospital for barium meal (69 patients), per oral cholecystography (50 patients), positive contrast herniography (12 patients), barium examination of the small bowel (7 patients), IVP (3 patients) and skeletal examination (2 patients). Seven non-dysphagial members of the staff of the Department of Diagnostic Radiology were also included.

No person included in the volunteers had had any earlier or present dysphagial sensation or disease that could suggest any disturbances in the swallowing act.

The examinations were performed with the aid of a cine-pulse unit and a Camématic GV Super high-speed cinecamera connected to a 9" x-ray image intensifier.

Cineradiograms of the act of swallowing were obtained at a speed of 50 and 100 frames per second in AP and lateral projections. The volunteers were instructed to swallow a large mouthful of contrast medium (Barytgen^R 60 % w/w) followed by one or several secondary swallowings for each series of frames.

The obtained cineradiograms were viewed on an analector unit (Steenbeck) facilitating a frame by frame analysis of the act of swallowing.

The movement pattern of the epiglottis was analyzed when the volunteers were swallowing a large mouthful of contrast medium and also when he/she cleared the pharynx from contrast medium remnants (secondary swallowing).

Results

Cineradiographically the following series of events could be registered. The tilting down of the epiglottis to cover the laryngeal inlet was accomplished as a clear-cut two-step procedure.

On swallowing, the larynx was elevated, the hyoid bone was approximated to the mandible and the distance between the hyoid bone and the thyroid cartilage was reduced (Figs 1 and 2).

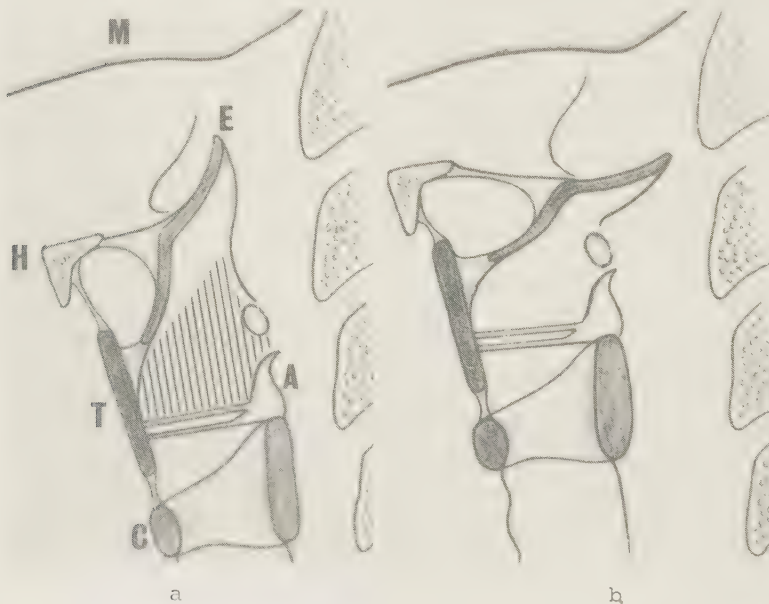


Fig. 1
(Text see
opposite
page)

Synchronously with the elevation of the larynx the epiglottis was tilted about 90° from its upright resting position to attain a transversal one with its free margin close to the posterior pharyngeal wall - *first epiglottic movement* (Figs 1 and 2).

During this movement the epiglottis maintained its hollow form with its concavity in the upward cranial direction. Simultaneously with the elevation of the larynx the bolus entered the pharynx where a peristaltic contraction was seen to start.

The epiglottis then tilted further down with its free margin displaced into the esophageal inlet - *second epiglottic movement* (Figs 2 and 3). During the latter movement the epiglottis changed in shape to an inverted caudal concave form. The inferior surface of the epiglottis was pressed against the ary region. The above described bilateral symmetric and synchronous pattern was registered in 137 volunteers. The second epiglottic movement was

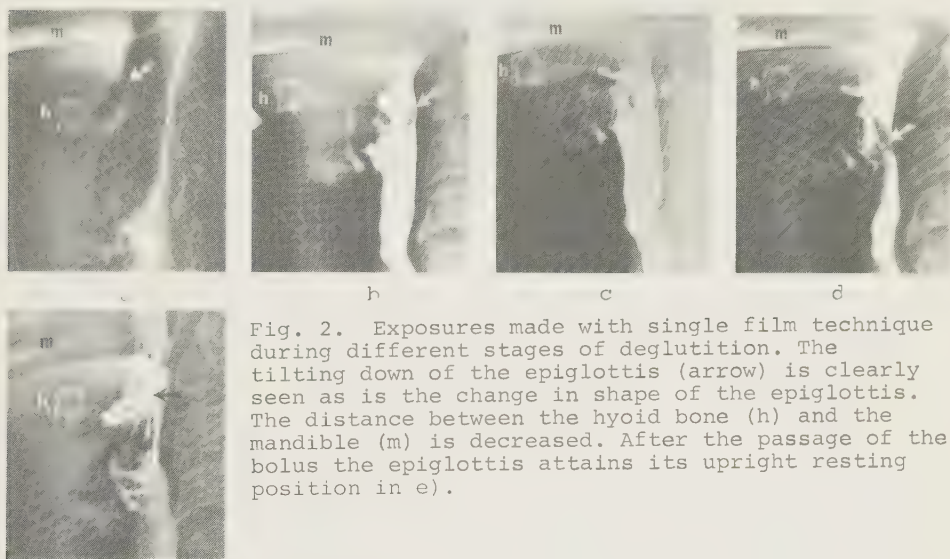


Fig. 2. Exposures made with single film technique during different stages of deglutition. The tilting down of the epiglottis (arrow) is clearly seen as is the change in shape of the epiglottis. The distance between the hyoid bone (h) and the mandible (m) is decreased. After the passage of the bolus the epiglottis attains its upright resting position in e).

Fig. 1. Schematic drawing of the larynx and pharynx seen from the left. a) in resting position. b) during elevation of the larynx. During swallowing the larynx is elevated seen as an approximation between the mandible and the hyoid bone and also between the thyroid cartilage and the hyoid bone. Due to its fixation and suspension to adjacent structures the epiglottis attains a transversal position. (A arytenoid cartilage, C cricoid cartilage, E epiglottis, H hyoid bone, M mandible, T thyroid cartilage. The hatched area represents the position of the quadrangular membrane.)

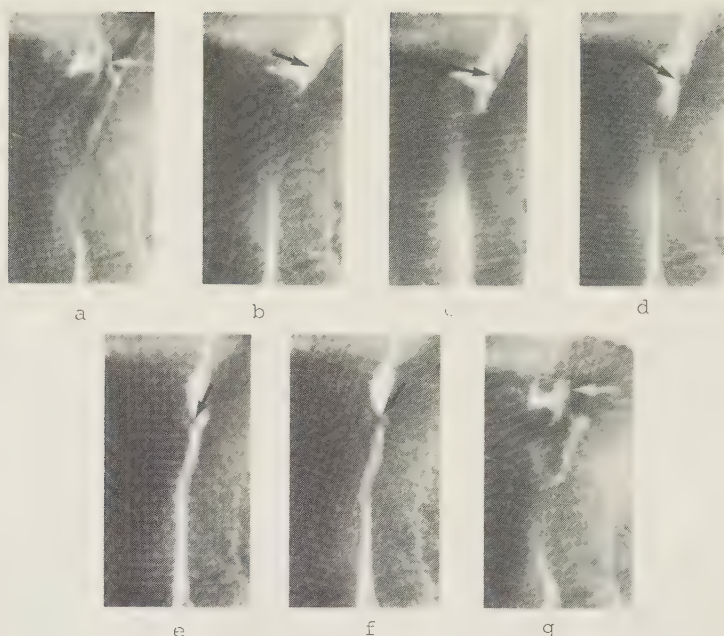


Fig. 3. Sequence from a cineradiographic examination. Lateral view. The epiglottis (arrow) is tilting down during swallowing. After the passage of the bolus the epiglottis attains its resting upright position in g).

absent among 7 volunteers. The epiglottis attained a 30° - 90° oblique position as seen in the frontal projection during its second movement among 6 volunteers (Table 1).

Table

Cineradiographic findings among 150 volunteers without dysphagia according to movement pattern of the epiglottis during deglutition.

Cineradiographic findings	Number of patients
Synchronous and symmetric pattern of movement of the epiglottis	137
Failure of the second movement of the epiglottis	7
30° - 90° obliquity of the epiglottis seen in the AP position	6
Total	150

Discussion

During the last century opinions have differed greatly about the function of the epiglottis during the act of swallowing. The renowned French physiologist Magendie (4) claimed that the epiglottis bent down over the laryngeal inlet during deglutition. In 1891 Anderson Stuart reported of a patient with a lateral pharyngostomy through which he could observe that the epiglottis remained upright during swallowing (5, 6). Cannon and Moser were the first ones to study the act of swallowing with x-ray technique and reported that the epiglottis was "pressed back during deglutition until it shuts the laryngeal aperture" (7). In 1927 Negus denied that the epiglottis moved during swallowing (8) while Mosher (9) claimed that it was tilted down and acted as a cover over the laryngeal inlet during deglutition. Barclay reported in 1930 (10) that fluoroscopic studies had convinced him that the epiglottis remained immobile during swallowing. Welin in 1939 (11) and Jonstone in 1942 (12) studied the epiglottis during deglutition. They used fluoroscopy of barium swallowing and both reported that on the passage of the bolus during swallowing the epiglottis bent down over the laryngeal aperture.

A thorough cineradiographic description of the act of swallowing was reported in 1951 by Saunders et al. (13). However, reports on cineradiography of deglutition had been published earlier (14, 15, 16). Saunders et al. could finally confirm the original statement of Magendie (4), that the epiglottis plays an active role during deglutition and that it was tilted down as a cover over the laryngeal inlet.

The divergent and from time to time changing opinions about the function of the epiglottis during deglutition may be explained by the distressing fact that the muscular anatomy of the epiglottis offers no obvious explanation of its function. This is true as long as the direction of the muscles is studied in the resting position of the epiglottis. In other words, there are no muscles that insert on the epiglottis in such a position that their contraction could explain the tilting down of the epiglottis during swallowing.

The fibroelastic cartilage of the epiglottis has the form of a racket, where the petiolus corresponds to the handle. The epiglottis is suspended to the adjacent structures by fibroelastic elements. The petiolus is attached by the thyroepiglottic ligament to the upper posterior aspect of the isthmus of the thyroid cartilage. The anterior aspect of the epiglottis is connected by the hyo-epiglottic ligament to the hyoid bone (Fig. 1). The epiglottic cartilage is suspended laterally to the quadrangular membrane. The upper boundary of this membrane is the aryepiglottic fold. Its lower boundary consists of the vestibular ligament, while the posterior boundary is the arytenoid cartilage (Fig. 1). This suspension of the epiglottis implies that movements of the thyroid cartilage and the hyoid bone are promptly transmitted to the epiglottis. Furthermore, a change in the mutual position between the thyroid cartilage and the hyoid bone is necessarily followed by a change in tension of the epiglottic cartilage and its suspending system followed by a change in position. An approach of these two structures to each other will tilt the epiglottis downwards to a transversal position while a following separation will return the epiglottis to its resting and upright position.

The first movement of the epiglottis is evidently a passive one, that is induced by the muscles that elevate the hyoid bone and approximates the thyroid cartilage to the hyoid bone. These muscles are stylohyoideus, digastricus, mylohyoideus, geniohyoideus, and thyrohyoideus. The epiglottis is bilaterally fixed by the pharyngoepiglottic plicae and is at the laryngeal elevation and thyrohyoid approximation tilted to a transversal position with these plicae as turning points (Fig. 1).

This concept of the first epiglottic movement - from the upright to the transversal position - is well compatible with the biomechanic theory presented by Fink (1, 2, 3). However, this theory according to which the epiglottis is folded down over the laryngeal inlet by a lateral compression combined with a cranial traction in the hyo-epiglottic ligament cannot completely explain the second and final movement of the epiglottis.

The second movement of the epiglottis from the transversal plane to a position with its tip in the esophageal inlet has been explained in different ways by different authors. Ramsey et al have suggested that the epiglottis is caught by the peristalsis of the pharyngeal constrictors and displaced down into the esophageal inlet (17). Bachmann (18) and Ardran and Kemp (19, 20), Rushmer et al (21) and Fink (1) have proposed that the bolus will press the epiglottis downward into the gullet. Neither of these theories seems to offer a satisfactory explanation of the second epiglottic movement in swallowing. The first one is inconsistent with the observation that the epiglottis in about half of our volunteers moved down before it was reached by the pharyngeal peristalsis. The second theory is contradicted by the fact that the epiglottis moves into the gullet even in a secondary swallowing without any bolus.

The first movement of the epiglottis seems to be a passive one, while the second movement may be the result of a muscular action directly on the epiglottis. The latter statement seems very probable as no other muscular activity can be seen in the surroundings of the epiglottis at the time of its second movement. Three muscles insert on the epiglottis in such a way that their contraction may change its position (Fig. 4).

These muscles are: the stylopharyngeal, the aryepiglottic and the thyroepiglottic (Fig. 4). The stylopharyngeal muscle emerges from the styloid process. The muscle passes in an anterior-inferior direction from the process between the superior and middle pharyngeal constrictors to the epiglottis and thyroid cartilage. The fan-shaped muscle also mingles with the palatopharyngeal muscle.

The aryepiglottic muscle passes beneath the plica aryepiglottica between the ary region and the lateral border of the epiglottis. The thyroepiglottic muscle emerges from the posterior surface of the thyroid cartilage in a posterior direction. The muscle is attached to the lateral border of the epiglottis and the aryepiglottic fold.

From Fig. 4 it is clear that neither of these muscles is able



Fig. 4. Schematic drawing of the pharynx and larynx seen from behind a), obliquely from the right and behind b), and from the right c). (a aryepiglottic muscle, s stylopharyngeal muscle, t thyroepiglottic muscle.)

to tilt the epiglottis down from its upright resting position. However, when the epiglottis by an elevation of the larynx and approximation of the thyroid cartilage to the hyoid bone has attained a transversal position with its tip in apposition to the posterior pharyngeal wall the conditions have changed (Fig. 5). The muscles that insert on the epiglottis, and which possibly could bring about the second movement down into the esophageal inlet, are the aryepiglottic and thyroepiglottic. The stylopharyngeal muscle can be excluded immediately as it, due to its position, possibly could elevate the epiglottis but never pull it down over the ary region. It is possible that the aryepiglottic muscle may be able to pull the epiglottis downwards against the ary region but never as far as into the esophageal inlet.

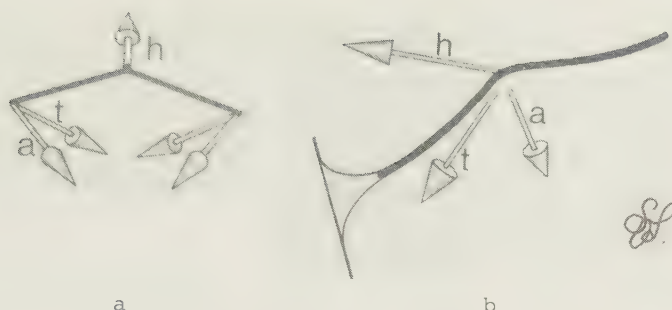


Fig. 5. Schematic drawing of the epiglottis in the transversal position. The epiglottis is seen from behind in a), and from the left in b). The supposed direction of three forces acting on the epiglottis are indicated. These forces are accomplished by the hyoepiglottic ligament (h), the thyroepiglottic muscle (t) and the ary epiglottic muscle (a). In b) the forces are accomplished by the muscles on the left side.

The remaining muscle, the thyroepiglottic which inserts on the epiglottis has, however, another action on the epiglottis when this has attained a transversal position than it has when it is in the resting and upright position. With the epiglottis placed in the transversal position a contraction of the thyroepiglottic muscle will pull the free portion of the epiglottis down over the ary region with its tip in the esophageal inlet. Furthermore, it will change the form of the epiglottis from a downward convex to an upward convex one. When the epiglottis has attained this new position a contraction of the ary epiglottic muscle will tighten the laryngeal inlet in the same manner as the string in a tobacco pouch.

The described mechanism will explain the complex function of the epiglottis during swallowing. Each of the muscles that inserts on the epiglottis has its specific action in the complex series of events that constitutes a protection of the laryngeal inlet during swallowing.

Abstract

The movements of the epiglottis during swallowing was studied in 150 volunteers without known swallowing complaints. During swallowing of a large mouthful of barium contrast medium followed by repeated secondary swallowings the examinations of the volunteers were performed with the aid of high-speed cineradiography. In 137 of the volunteers the epiglottis tilted down in a two-step fashion during deglutition. The first movement from upright to the transversal position was accomplished by the lifting of the larynx and the approximation between the hyoid bone and the thyroid cartilage. This first movement is evidently a passive one that is induced by the muscles that accomplish the lifting of the hyoid bone. The second movement of the epiglottis, from the transversal to the inverted position, occur later in the swallowing act. This second movement seems to be the result of a contraction of the thyroepiglottic muscle. When the epiglottis is in the transversal position this muscle has a favourable action on it. A contraction of the aryepiglottic muscle, at this stage could enforce the inversion of the epiglottis and especially the change in shape to an inverted concave form at the end of the tilting down.

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EPIGLOTTIC DYSFUNCTION DURING DEGLUTITION IN PATIENTS WITH
DYSPHAGIA

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The function of the epiglottis during deglutition has been treated at length in the literature (1, 2, 3, 4, 5). Some reports have claimed it to have an important role in protecting the laryngeal inlet, others have denied it to have any function at all in the act of swallowing. However, according to modern concepts the epiglottis is assigned an important, but not essential, function in the act of swallowing (5). In a previously performed cineradiographic investigation of the act of swallowing in patients with dysphagia a dysfunction of the epiglottis was a common finding, i.e., the epiglottis showed an aberrant motion pattern during deglutition (6). The purpose of the present investigation was to analyse the motion patterns of the epiglottis in these patients during swallowing and to disclose the pathophysiologic significance of the epiglottic dysmotility.

Material and Methods

The material was obtained from a group of 250 patients consecutively subjected to cineradiography of pharyngeal deglutition due to dysphagia. A review of these patients' cineradiographies revealed 83 in which an aberrant movement pattern of the epiglottis was registered during deglutition.

The material proper thus consisted of 83 patients, 47 male and 36 female, aged between 24 and 93 years (mean age 66 years). The patients had prior to the cineradiography been subjected to a thorough routine X-ray examination. This included fluoroscopy, plain films in different projections before and after barium swallowing as well as films taken during barium swallowing.

The cineradiograms were obtained with the aid of a Camématic GV 16 Super camera and a cine-pulse unit. Exposures were made at 80 kV and with a maximum mA of 125. The exposure time for each frame varied between 1 and 5 msec. Films were obtained at a speed of 50 and 100 frames per second. Every cineradiographic examination included as a minimum two AP and two lateral views with the patients in the erect position. To obtain an optimal recording of the act of swallowing the patients were instructed to swallow

a large mouthful of a barium contrast suspension (Barytgen^R 60 % w/w). After this initial barium swallowing the patients were asked to perform repeated swallows in order to register their mode of dry swallowing with a thin layer of barium contrast medium coating the mucosa. The obtained cineradiograms were analysed with the aid of a cine-film analector (Steenbeck ST 1100) and scrutinized for aberrations in the movements of the epiglottis. Concomitant abnormalities in the act of swallowing were registered as well. An interruption of the peristalsis in the pharyngeal wall was interpreted as a pharyngeal constrictor muscle paresis of varying degree according to the extension and position of the abnormality. An indentation in the posterior wall of the pharyngoesophageal junction due to the cricopharyngeal muscle at a moment when the cervical esophagus was well distended by the bolus was interpreted as a dysfunction (achalasia). When contrast medium entered the laryngeal vestibule this was regarded as misdirected swallowing. The presence of Zenker pouches and cervical esophageal webs was also registered.

Results

A totally immobile epiglottis during deglutition was seen in 19 patients (Fig. 1). Eleven of these patients had a concomitant pharyngeal constrictor paresis of varying degree. In 4 patients the paresis was almost complete and in 7 the paresis involved the middle pharyngeal constrictor only. Sixteen of these patients with an immobile epiglottis had also contrast medium entrance into the vestibule, i.e., a varying amount of contrast medium entered the laryngeal vestibule and in 12 patients also to some extent the trachea. A severely impaired or absent second movement of the epiglottis with its first movement intact was registered in 53 patients (Fig. 2). Of these patients 2 showed an almost complete pharyngeal constrictor muscle paresis while 11 had a circumscribed paresis of the middle pharyngeal constrictor. In 45 patients a misdirected swallowing was encountered as well. In the remaining 8 patients no contrast medium entered the vestibule. In 11 patients the epiglottis attained an oblique position varying between 30 and 90 degrees as seen in the AP projection during its

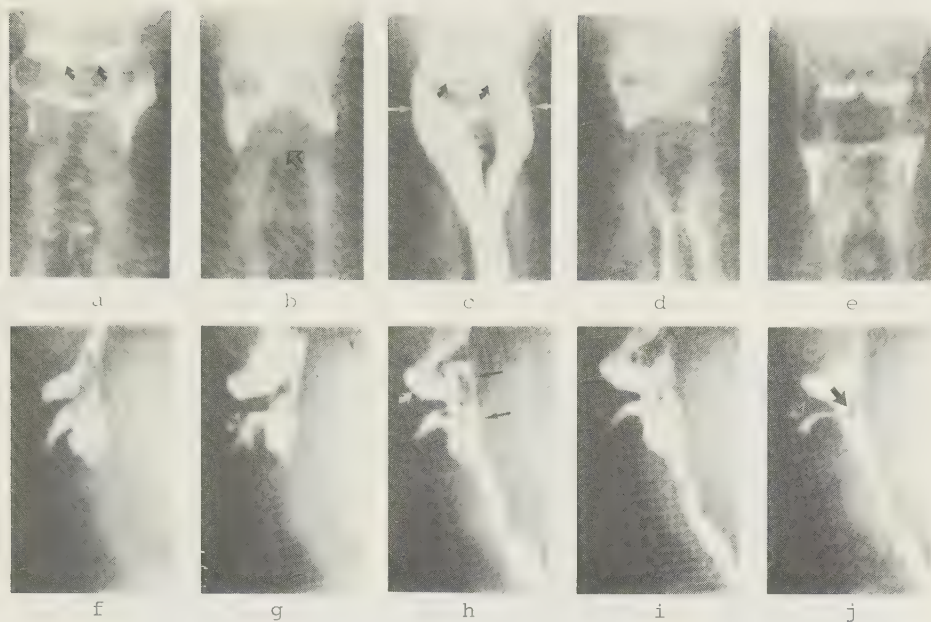


Fig. 1. a-e AP view, f-j lateral view. Sequence from a cine-radiographic examination. The valleculae (bent arrows) are not effaced in the AP view due to the immobility of the epiglottis. The epiglottis attains a somewhat accentuated upward concavity (thick arrow) but does not tilt down. No contraction is observed in the pharyngeal constrictor musculature (thin arrows). Contrast medium has entered into the laryngeal vestibule (open arrow).

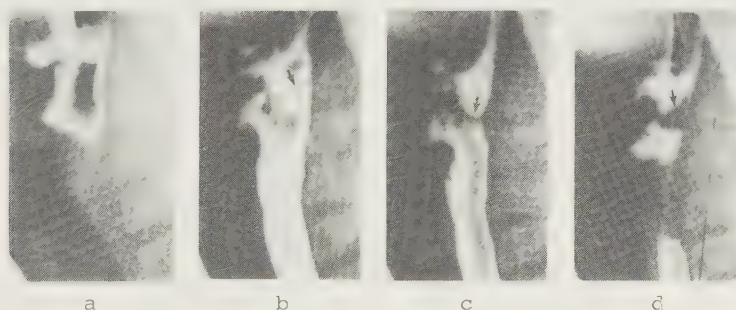


Fig. 2. Sequence from a cineradiographic examination. Lateral view. The epiglottis (arrow) is tilting down to the transversal position, but not further down.

second movement when it was tilted down to the inverted position (Fig. 3). In 4 of these patients contrast medium entered the superior uppermost portion of the vestibule, also called the subepiglottic space. Epiglottic dysfunction was seen together with other dysfunctions in the swallowing act in 71 of the 83 patients in this series (Table 1). A summary of the results of epiglottic dysfunction according to misdirected swallowing is given in Table 2.

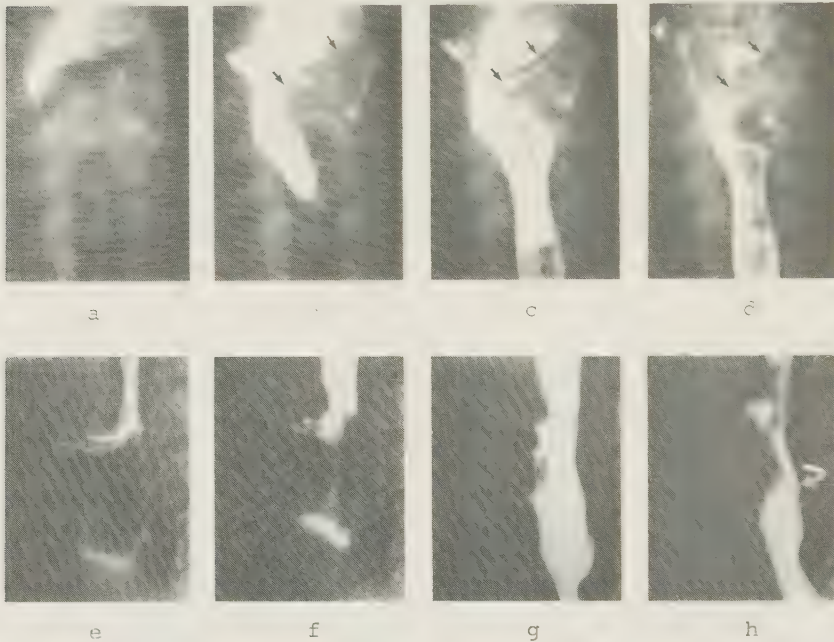


Fig. 3. a-d AP view, e-h lateral view. Sequence from a cineradiographic examination. The epiglottis (arrows) attains an obliquity of about 60° as seen in the AP views. The tip of the epiglottis (bent arrow) tilts down reaching into the esophageal inlet.

Concomitant abnormalities	Types of dysfunction of the epiglottis. N = 83		
	Immobility n = 19	Impaired second movement n = 53	Obliquity n = 11
Pharyngeal constrictor paresis	11	13	1
Misdirected swallowing	16	45	4
Cricopharyngeal dysfunction	4	12	1
Webs	2	5	0
Zenker pouches	0	1	0
No concomitant abnormalities	2	5	5

Table I

Types of dysfunction of the epiglottis during swallowing and concomitant abnormalities.

Laryngeal vestibule during deglutition	n = 83. Dysfunction of the epiglottis during deglutition		
	immobile epiglottis n = 19	impaired second movement n = 53	30-90 degrees n = 11
Normal	3	8 ^x	13
Impaired closing of the subepiglottic space	3 ^x	25 ^y	4
Impaired closing of the supraglottic space	1	5	0
Impaired closing of the supraglottic space with contrast medium passing into the trachea	12	15 ^y	0

^x including one with aspiration to the trachea

^y including two with aspiration to the trachea

Table II

Different abnormalities in epiglottic function during deglutition according to the protection of the laryngeal vestibule as seen as the presence of contrast medium in the vestibule and/or the trachea.

Discussion

In a previous investigation, from which the material of the present report has been obtained, 33 percent of the patients with dysphagia were shown to have a deglutitional epiglottic dysfunction (6). This figure should be compared to an incidence of 9 percent of epiglottic dysfunction reported in nondysphagial normal volunteers (7, 8). Thus, epiglottic dysfunction was four times more common in patients with dysphagia than in normal individuals. Obliquity of the epiglottis as registered in the AP projection was found in 6 of the 150 volunteers (4 %) and in 11 of the 250 dysphagial patients (4.4 %) in the above cited series (6). If this entity is excluded the frequency of epiglottic dysfunction can be calculated in nondysphagial volunteers and dysphagial patients to be 5 and 29 percent, respectively. This means that proper epiglottic dysfunction is significantly more common among dysphagial patients than in nondysphagial volunteers ($p < 0.001$). This observation strongly suggests a causal relationship between epiglottic dysfunction and the subjective sensation of dysphagia.

Epiglottic motility can be studied by the aid of radiography and especially cineradiography (8). However, conventional films only seldom give enough information to ascertain the diagnosis of epiglottic dysfunction.

The movements of the epiglottis during swallowing can of course be studied by fluoroscopy and the radiologist can obtain certain clues to the correct diagnosis. However, fluoroscopy is difficult and impractical because of the rapid movement of the epiglottis. The time lapse for the first movement of the epiglottis from its resting upright position to the transversal position has been registered to be about 0.16 sec. The second movement, from transversal to the inverted position in the esophageal inlet takes about 0.20 sec. The time lapse for the epiglottis to return to its resting upright position has been estimated to about 0.22 sec. (7). Due to the high velocity of the movements it is not possible to observe more than just one single movement at a time. This must be done under the most careful screening (fluoroscopy and exposures) of repeated swallowings. This implies that a

thorough examination requires a large volume of contrast medium which can be very unpleasant for the patients. Fluoroscopy also requires an experienced radiologist, is time-consuming, gives the patient a fairly high dose of radiation and cannot be repeated after the patient has left the department. Cineradiography according to the used method offers a convenient method for examination of patients with dysphagia and offers a low dose of radiation.

The cineradiographic diagnosis of epiglottic dysfunction is based on the appearance of the epiglottis in both AP and lateral projections. In the lateral projection it is usually easy to recognize the epiglottis when it is tilting down to the horizontal position, even if the epiglottis is hidden by the passing bolus which happens occasionally. This disadvantage is overcome by the fact that the epiglottis normally does not attain its resting upright position until the bulk of the bolus has passed into the esophagus. For this reason it is always possible to discern the tip of the epiglottis and thus to ascertain that it has tilted down. In the AP projection it is usually also possible to assess the movements of the epiglottis. It can easily be resolved if the epiglottis remains in its transversal position during the whole act of swallowing, i.e., impaired second epiglottic movement. The valleculae are easily identified on an AP projection as a certain amount of contrast medium always remains at the bottom. Under normal conditions the valleculae are effaced when the epiglottis is tilted down to its inverted position with its tip in the esophageal inlet. However, in patients where the second movement of the epiglottis is defective the radiographic pattern of the valleculae remains visible throughout the whole act of swallowing. (Fig. 1). In the AP projection it is also possible to disclose any obliquity of the epiglottis but as this was not accompanied by any other dysmotility it is probably not of pathologic significance (Fig. 3).

From the result it is clear that 4 of the 11 patients with an obliquity of the epiglottis on swallowing also showed a contrast medium entrance into the subepiglottic space of the vestibule. This phenomenon was probably a consequence of the epiglottic

obliquity. Contrast medium slipped round the epiglottis at a moment when the subepiglottic space had not yet been closed.

Dysfunction of the epiglottis has been described among "normal" individuals without dysphagia (7). However, among these the epiglottic dysfunction was usually an isolated phenomenon and not accompanied by other abnormalities in the act of swallowing. On the other hand, in the present investigation of patients with dysphagia epiglottic dysfunction was often found to be concomitant with other aberrations, i.e., pharyngeal constrictor paresis, misdirected swallowing, cricopharyngeal incoordination, Zenker diverticula and webs. The high frequency of concomitant abnormalities in the act of swallowing suggests a common pathophysiologic background. The swallowing center in the medulla, including the nucleus ambiguus, is responsible for the transmission of afferent sensory impulses from the mucosa in the pharynx and mouth to efferent motor activity via the ninth, tenth and eleventh cranial nerves. Any lesion in these centers might possibly induce an epiglottic dysfunction. However, this dysfunction seems to be rather circumscribed, an observation that suggests a lesion much nearer the effector organ, the epiglottis, than assumed above. It is possible that patients with extensive abnormalities in the act of swallowing, i.e., pharyngeal constrictor paresis, cricopharyngeal incoordination and misdirected swallowing, may have a bulbar lesion while patients with circumscribed dysfunctions in the movement of the epiglottis more probably suffer from regional neuronal or muscular pharyngeal lesions. So far no localized muscular abnormalities have been described which could have caused the reported regional dysfunction of the epiglottis. However, general motor neuronal diseases have been described in connection with abnormalities in the act of swallowing (9, 10).

From this study no definite conclusion can be drawn about the importance of epiglottic tilting down over the superior aperture of the larynx as a shelter for the airways. From the results of the present investigation it is evident that a defective tilting down of the epiglottis did not inevitably lead to misdirected swallowing, suggesting that the vestibule can be protected by a mechanism other than the tilting down of the epiglottis. A proper

function of the thyroepiglottic muscle could be included in such a mechanism (8). Another explanation of this observation about discrepancy in the recognition of epiglottic dysfunction and misdirected swallowing may be that the thyroepiglottic muscle by contraction can appose the fixed part of the epiglottis to the ary region without a tilting down of the epiglottis. The thyroepiglottic muscle partly inserts also on the fixed part of the epiglottis and this part of the muscle may act properly whereby the epiglottis is apposed to the ary region.

In an earlier report on the normal act of swallowing it has been shown that epiglottic dysfunction sometimes may be seen in apparently healthy individuals without any swallowing complaints (7). Thirteen individuals included in the quoted investigation of 150 nondysphagial volunteers showed epiglottic dysfunction but only 2 of them had a misdirected swallowing. This finding should be compared to the results of the present investigation of patients with dysphagia in which 69 out of 83 (83%) with epiglottic dysfunction also showed one or more concomitant functional aberration in the act of swallowing.

From these findings is clear that epiglottic dysfunction as an isolated phenomenon is rare in asymptomatic individuals but is fairly common in patients with dysphagia. In these patients a causal relationship between the epiglottic dysfunction and the dysphagial complaints seems to be very likely. It is furthermore clear that epiglottic dysfunction very often appear together with other deglutitional dysfunctions and under these circumstances invariably in patients with dysphagia.

Abstract

Among 250 patients with dysphagial complaints 83 had dysfunction of the epiglottis as revealed by high-speed cineradiography. Nineteen patients had a totally immobile epiglottis and of these 11 had concomitant pharyngeal constrictor paresis of varying extension and severity. Sixteen of the patients with immobile epiglottis had misdirected swallowing even to the level of the trachea. An absence of the second movement of the epiglottis, during deglutition was registered in 53 patients. Thirteen of

these had pharyngeal constrictor paresis and 45 misdirected swallowing. In 11 patients the epiglottis attained an obliquity of 30 - 90 degrees as seen in the AP projection during its second movement. One of these had a pharyngeal constrictor paresis while 4 had misdirected swallowing. The results of this study indicate that epiglottic dysfunction is common among patients with dysphagia and is often accompanied by other functional abnormalities. The diagnosis of the epiglottic dysfunctions requires a meticulous technique and is not possible without the aid of high-speed cine radiography.

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CLOSURE OF THE LARYNGEAL VESTIBULE DURING DEGLUTITION

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The protection of the airways during deglutition to avoid contamination by the bolus is accomplished by means of three distinct mechanisms, namely: obturation of the rima glottidis, closure of the laryngeal vestibule and a tilting down and inversion of the free movable part of the epiglottis. The aim of the present investigation was to study the closure of the laryngeal vestibule with high speed cineradiography in normal individuals and to elucidate the morphologic conditions and different functional mechanisms behind the closure of the laryngeal vestibule.

Material and Methods

The material consisted of 150 cineradiographies of the swallowing act obtained from the same number of volunteers (79 males and 71 females). These were aged 20 - 82 years with a mean age of 52 years. The volunteers were recruited from patients referred to the X-ray Department of Malmö General Hospital for barium meal (69 patients), peroral cholecystography (50 patients), positive contrast herniography (12 patients), barium examination of the small bowel (7 patients) intravenous pyelography (3 patients) and skeletal examination (2 patients). Seven healthy members of the staff of the Radiologic Department were also included. The persons included among the volunteers denied any earlier or present dysphagial sensation or disease that could indicate any disturbances in the swallowing act.

Cineradiograms of the act of swallowing were obtained with a speed of 50 and 100 frames per second in AP and lateral views. The volunteers were instructed to swallow a large mouthful of contrast medium (Barytgen^R 60 % w/w) followed by one or several secondary swallowings for every series of frames.

The obtained cine-radiograms were viewed on an analector unit (Steenbeck) with the facility of a frame by frame analysis of the act of swallowing.

The cine-films were scrutinized regarding the function of the pharyngeal constrictor musculature, the cricopharyngeal muscle,

the epiglottis and the laryngeal vestibule. Attention was also paid to the presence of functional webs and pouches.

Anatomical considerations

The laryngeal vestibule constitutes the airfilled cavity between the vocal folds and the pharynx (Fig. 1). Its cranial border is made up of the free margin of the epiglottis, the aryepiglottic folds and the arytenoid region with the interarytenoid incisure. The anterior wall and the roof of the vestibule

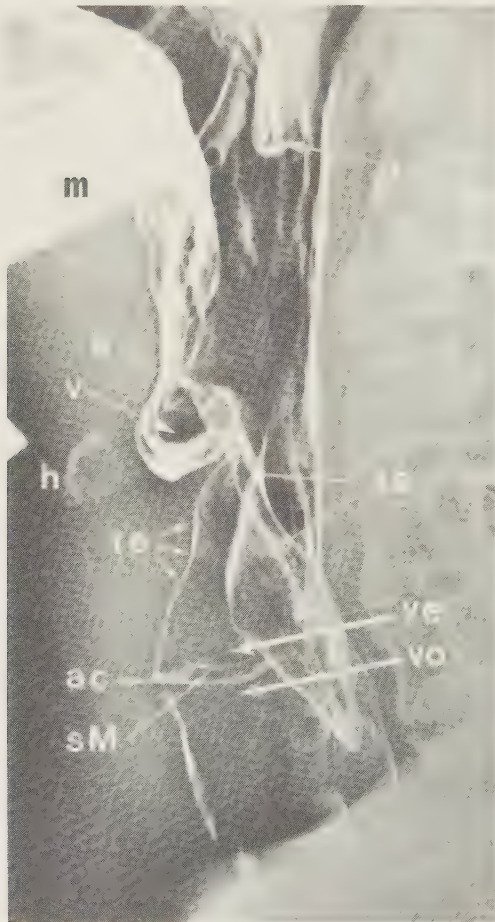


Fig. 1

Lateral radiogram of the pharynx and larynx. Resting position, (ac anterior commissure, ae aryepiglottic fold, e epiglottis, h hyoid bone, m mandible, sm sinus of Morgagni, te tubercle of epiglottis, u uvula, v vallecula, ve ventricular fold, vo vocal fold).

is composed of the posterior aspect of the epiglottis, its movable as well as its fixed portion and a fat cushion covering the thyroid cartilage down to the level of the anterior laryngeal commissure. The side-walls are composed of the thyroid cartilages and the overlying structures, i.e, the thyroepiglottic and thyroarytenoid muscles on each side. The inferior part of the latter muscle is composed of a medial segment -the vocal muscle - and a lateral segment. The superior part constitutes the ventricular muscle. Between these two muscles - the vocal and the ventricular - there is a bilateral recess formation known as the laryngeal ventricles or the sinuses of Morgagni. The thyroepiglottic muscles form a continuation in cranial direction of the thyroarytenoid muscles, but are more laterally situated. The laryngeal ventricles constitute the caudal border of the lateral walls of the vestibule.

The vestibule can be described as a bent tube at an angle of about 45 degrees. This angulation divides the vestibule anatomically into a cranial and a caudal segment, a subdivision that is valid also from a functional point of view. This will be accounted for later in this report. The cranial segment, subsequently denoted the *subepiglottic space* is separated from the caudal segment, subsequently denoted the *supraglottic space*, by an imaginary plane between the interarytenoid incisure and the incisure of the thyroid cartilage (Fig. 2). This subdivision of the vestibule corresponds roughly to the position of the adjacent muscles especially the thyroarytenoid muscle lateral to the supraglottic space and the thyroepiglottic muscle lateral to the subepiglottic space. As will be shown in this report these muscles contribute to the closure of the vestibule in different ways during different stages of the swallowing act.

Results

The following series of events were registered during the swallowing act (Figs 3 and 4): When the bolus entered the mesopharynx through the fauces pharyngis the larynx was lifted cranially, the hyoid bone was approximated to the mandible and the distance between the hyoid bone and the thyroid cartilage was

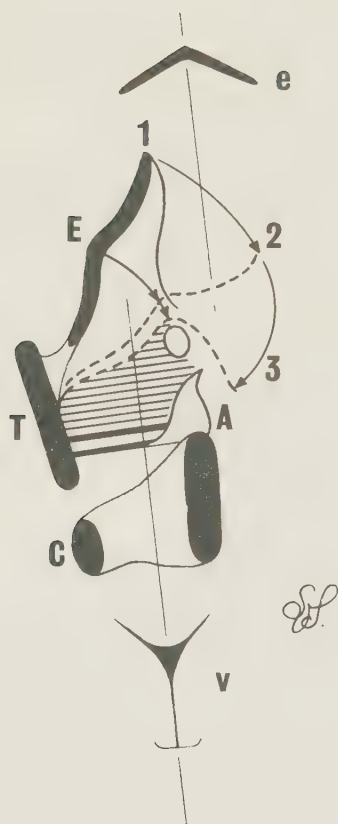


Fig. 2.

Schematic drawing of the larynx seen from the left. The epiglottis is reproduced in its three positions: 1. resting upright, 2, horizontal and 3, inverted position. The hatched area of the vestibule represents the closed supra-glottic space. (A arytenoid cartilage, C cricoid cartilage, E epiglottis, T thyroid cartilage, e the horizontally positioned free lip of the epiglottis seen in the coronal plane, v the closed vestibule seen in the coronal plane).

(Drawing by
S.V. Sigurjónsson, M.D.)

considerably reduced. Synchronously with this lifting the plicae vocalis were apposed so that the rima glottidis was closed. Simultaneously with this, and normally indistinguishable from it, the plicae ventricularis were apposed and the ventricular sinus compressed. These events were best recognized in the AP projections but were also recognized in the lateral projection. In immediate connection to the closure of the rima glottidis there was also a closure of the supra-glottic space. This closure was caused by an apposition of the lateral walls. During this stage of the swallowing act the epiglottis bent down to a transversal

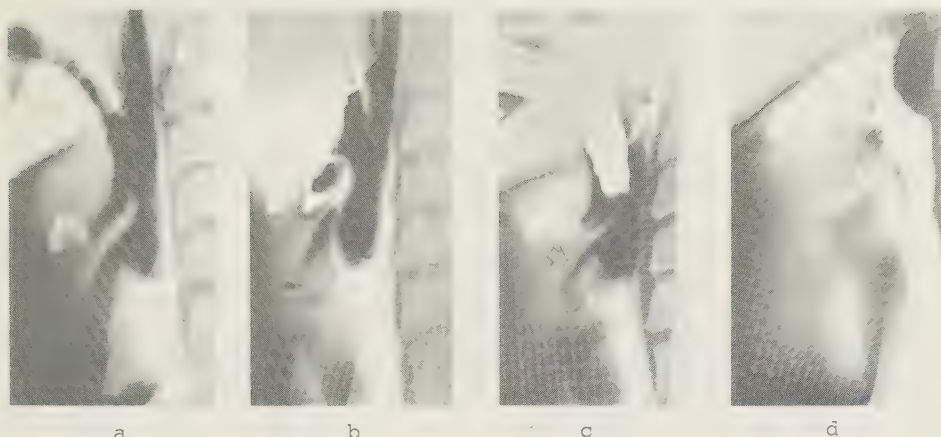


Fig 3. Conventional single film exposures obtained during different stages of deglutition. In a) the vestibule is open and filled with air. In b) the supraglottic space (arrow) has closed. In c) the subepiglottic space (open arrow) has been partly closed. In d) the whole vestibule is closed.

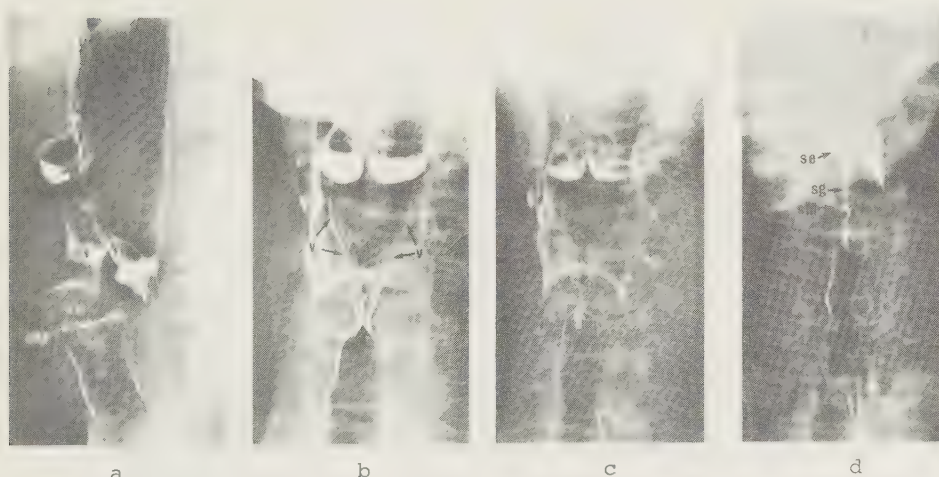


Fig 4. When contrast medium is present as a thin coating of the mucosa the closure of the vestibule can be clearly seen also in the PA projection. In a) the location of the contrast medium is seen in lateral projection. The supraglottic space is closed and the contrast medium has been almost completely expressed. In b) the rima glottidis (arrow) and supraglottic space is open. In c) the rima is closed while the supraglottic space is still open. In d) the supraglottic space is closed, while the subepiglottic space is still open. (sm sinus of Morgagni, v barium contrast coating of the vestibular mucosa, se subepiglottic space, sg supraglottic space).

position with its tip in apposition to the posterior pharyngeal wall. In the meantime the apex of the bolus usually had passed to or beyond the level of the epiglottis. During this stage it was often seen that the subepiglottic space was kept open. The movable part of the epiglottis was then tilted down over the arytenoids. By this manoeuvre the subepiglottic space was compressed in a superior-inferior direction by the apposition between the fat cushion of the fixed part of the epiglottis and the arytenoids.

Discussion

Stuart Anderson in 1891 was able to study the superior laryngeal aperture in a patient who had had a large part of the lateral wall of the pharynx removed due to carcinoma. He observed that the inlet at swallowing was closed due to an apposition of the arytenoids and also by a simultaneous apposition between the arytenoids and the fat cushion of the epiglottis. He stated that the vestibule was closed from above and downwards. He proposed that the lateral part of the thyroarytenoid muscle was the true and only "sphincter vestibulae". Stuart Anderson's observations were supported by both anatomic and radiologic investigations (Negus 1929; Mosher 1927). However, Negus in 1929 seems to have paid more attention to the sphincteric activity in the superior laryngeal aperture and ascribed this to be due to contraction of the paired cricoarytenoid and thyroarytenoid muscles and the unpaired interarytenoid muscle (Negus 1929). Barclay in 1930 made radiologic observations and proposed that the lifting of the pharyngeal musculature caused the loosely attached mucosa of the anterior wall of the postcricoid part of the pharynx to fold over the arytenoids and against the base of the epiglottis. In this way the mucosa was drawn over the superior laryngeal aperture like a curtain (Barclay 1930). The earlier proposed protection of the larynx by both compression of the vestibule and a sphincteric activity in the superior laryngeal aperture was supported by cineradiographic observations performed by Saunders et al. in 1951. This opinion was further elaborated by Pressman and Kelemen in 1955 who considered that the closure of the vestibule was achieved by three sphincters, namely, the vocal folds, the

ventricular folds and the superior laryngeal aperture muscles (Pressman & Keleman 1955). Rushmer et al. in 1951 who had performed cineradiographic observations of the act of swallowing had proposed that the vestibule did not close but that the airways were protected by a "vapor lock" in the vestibule above the closed rima glottidis (Rushmer & Hendron 1951). This statement seems to have been supported by Ardran and Kemp in 1952. Later, however, they abandoned this explanation for the protection of the vestibule and proposed instead that the vestibule was closed and this was accomplished from below (Ardran & Kemp 1956). However, for long time they seemed to have favored the opinion, expressed by Johnstone in 1942, of an open rima glottidis through which air from the vestibule could escape when the vestibule was closed (Jonstone 1942; Ardran & Kemp 1967). They claimed that the closure was dependent only on extrinsic muscle activity, i.e., the lifting of the larynx towards the hyoid bone (Ardran & Kemp 1967), thus denying the importance of the intrinsic muscles of the larynx. Ramsey et al in 1955 studied deglutition with cineradiography and seem to have been the first ones to stress that the vestibule was closed with a peristaltic activity from below. Bachman in 1959, on the other hand, came to the opposite conclusion, namely that the vestibule was not closed at all during deglutition.

The results from the present study, performed with high speed cineradiography, indicate that it is possible to distinguish two different steps in the closure of the vestibule, both of which are clearly separated from the closure of the rima glottidis. In the first step the supraglottic space of the vestibule is closed by the apposition of the lateral walls. This closure of the supraglottic space is caused by contraction and thickening of the superior portion of the thyroarytenoid muscle. The compressed supraglottic space has an orientation in the sagittal plane (Figs 2 and 4).

In the second step the closure of the vestibule is effected by a compression of the subepiglottic space from above which is caused by the tilting down of the epiglottis. Its tip is turned down into the esophageal inlet. By this mechanism the epiglottis

is gradually pressed against the prominence of the elevated ary region. The compressed subepiglottic space has an orientation nearly in the horizontal plane with its anterior part more caudal than the posterior part. The tilting of the epiglottis is probably the result of a contraction of the thyroepiglottic muscles. A backward bulging of the superior - anterior wall of the vestibule is achieved by a folding of the median soft tissue linking the thyroid cartilage to the hyoid bone. This tissue comprises the epiglottic cartilage, the pre-epiglottic fat cushion and its bounding ligaments, namely, the thyroepiglottic, the median thyrohyoid and the hyoepiglottic ligaments. In analogy with other folds in this region the above structures have been designated "the median thyrohyoid fold" (Fink 1976).

The described sequence of events in the closure of the vestibule by a compression from below - the supraglottic followed by the subepiglottic space - is important as it implies a peristaltic-like mechanism that can clear the vestibule from bolus material. After a swallowing act the vestibule is free from foreign particles when it opens again.

A few individuals without any dysphagial sensations subjected to cineradiography of the act of swallowing had contrast medium entrance into the subepiglottic space (Ekberg & Nylander 1981). This contrast medium was however immediately and almost completely returned into the mesopharynx as the subepiglottic space was compressed.

The present investigation has shown that the laryngeal vestibular closure is very efficient in blocking contrast medium during deglutition and this finding is supported by the fact that there is a very rich sensory innervation in the laryngeal vestibule (Anderson 1891; Pressman & Keleman 1955). This seems to be very appropriate as even a small amount of foreign particles initiates vestibular closure (Anderson 1891). As the peristaltic wave starts from below particles will not be lodged in the vestibule and will not be displaced into the trachea but pressed back into the pharynx.

Abstract

With the aid of high-speed cineradiography (up to 100 frames per second) the closure of the laryngeal vestibule during deglutition was studied in 150 volunteers without swallowing complaints. The closure was observed to be effected by a peristaltic-like wave from below. This was accomplished in two steps. First the caudal segment of the vestibule, the *supraglottis space*, was closed by an apposition of the side walls. Then the cranial segment of the vestibule, the *subepiglottic space*, was closed by an apposition of the fixed part of the epiglottis to the ary region. The subdivision of the vestibule was made by an imaginary plane between the interarytenoid incisure and the incisure of the thyroid cartilage. This subdivision corresponds to the location of the thyroarytenoid muscles lateral to the supraglottic space and the thyroepiglottic muscles lateral to the subepiglottic space. In this way the two muscle pairs contribute in different and distinct ways to the closure of the vestibule during deglutition.

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DEFECTIVE CLOSURE OF THE LARYNGEAL VESTIBULE DURING DEGLUTITION

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The airways are protected from the bolus during deglutition. This is accomplished by an obturation of the rima glottidis, a closure of the laryngeal vestibule and by a tilting down of the epiglottis. Inadequate protection of the airways may allow part of the bolus to pass into the lungs with pulmonary complications as a potential consequence.

The closure of the laryngeal vestibule is probably the most important factor in the protection of the airways. In a previously reported investigation this closure was studied in 150 volunteers without swallowing complaints (Ekberg 1981). Among these the closure was the result of a peristaltic-like action from below in 142 individuals in whom no part of the bolus entered the vestibule. Small amounts of contrast medium primarily passed into the cranial part of the vestibule in 8 volunteers. However, during the subsequent course in the act of swallowing the vestibule was closed and the contrast medium was then promptly returned into the mesopharynx. The result of this earlier investigation justifies the assumption that under normal conditions closure of the vestibule only rarely is insufficient and that part of the bolus only rarely finds access to the vestibule.

A subdivision of the laryngeal vestibule according to functional and anatomical conditions was proposed in the above mentioned report (Ekberg 1981). This subdivision is made by an arbitrary plane extending from the interarytenoid incisure to the thyroid cartilage, thereby dividing the vestibule into a superior and an inferior space. The superior space is demarcated by the plane and the aryepiglottic fold and is called the *subepiglottic space*. The inferior space is demarcated by the plane and the rima glottidis and is called the *supraglottic space*.

The purpose of the present investigation was to study a group of patients with defective closure of the laryngeal vestibule during swallowing in order to find out whether high-speed cine-radiography could elucidate details in the pathophysiology of the vestibule in these patients.

MATERIAL AND METHODS

The material was obtained from a group of 250 patients consecutively subjected to cineradiography of pharyngeal deglutition due to dysphagia. A review of these patients' cineradiograms revealed 103 (41 %) in whom a defective closure of the vestibule was registered (Ekberg & Nylander 1981 b).

The material proper thus consisted of 103 patients, 53 males and 50 females, aged between 24 and 93 years (mean age 66.5 and 65.2 years, respectively). The patients had prior to cineradiography been subjected to a thorough routine x-ray examination. This included a careful fluoroscopy, plain films in different projections before and after swallowing as well as films taken during barium swallowing.

The cineradiograms were performed with the aid of a Camëmatic GV 16 Super camera and a Philips cine-pulse unit. Exposure were made at 75-80 kV, 125 mA and with an exposure time for each frame of 1-5 msec. Films were obtained with a speed of 50 and 100 frames per second.

Every cineradiographic examination comprised at least two AP and two lateral series, respectively.

To obtain an optimal recording of the act of swallowing the patients were instructed to swallow a large mouthful of a barium contrast suspension (Barytgen^R 60 % w/w). After this initial barium swallowing the patients were asked to perform repeated swallows in order to register their mode of dry swallowing with a thin coating of barium contrast medium on the pharyngeal mucosa.

The obtained cineradiograms were analyzed with the aid of a cinefilm analector (Steenbeck ST 1100) and scrutinized for aberrations in the act of swallowing. Special attention was paid to the closure of the vestibule on swallowing as it was visualized in the cineradiograms regarding the presence and disappearance of air in the vestibule and the passing of contrast medium into the

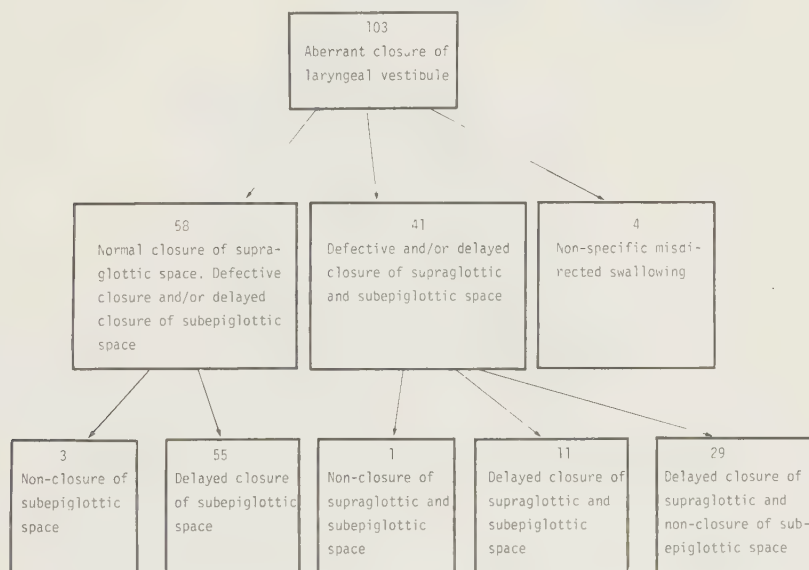
vestibule. Concomitant aberrations in the act of swallowing were also registered, i.e., pharyngeal constrictor paresis, epiglottic dysmotility, incoordination of the cricopharyngeal muscle, webs and Zenker diverticula.

RESULTS

A brief summary of the obtained results is outlined in Fig. 1.

In all the 103 patients the rima glottidis exhibited a normal closure within the usual time when the larynx was elevated at the beginning of the swallowing act.

Fig. 1. Distribution of 103 patients with a defective closure of the vestibule according to the cineradiographic findings.



The dysfunction of the laryngeal vestibule varied in degree from one patient to the other. In 58 patients the closing of the supraglottic space was normal but the subepiglottic space did not close properly. Consequently, on swallowing the vestibule was filled with contrast medium down to the border of the supraglottic space (Fig. 2).



Fig. 2. Sequence from a cineradiographic examination. Lateral view. In a) the vestibule is open (open arrow). Contrast medium enters into the subepiglottic space of the vestibule (arrow). The epiglottis (bent arrow) tilts down to an almost horizontal position.

In 3 of these 58 patients the subepiglottic space remained patent through the subsequent act of swallowing. In the remaining 55 patients the subepiglottic space closed later during the act of swallowing. These 55 patients had evidently a delayed but otherwise normal closing of the subepiglottic space. In these patients the subepiglottic space was closed gradually from below and its content of contrast medium was rejected into the mesopharynx. After the swallowing a thin contrast medium coating remained on the mucosa of the vestibule (Figs 3 and 4).



Fig. 3. Sequence from a cineradiographic examination. lateral view. Contrast medium enters into the vestibule (thick arrow) even to the level of the sinus Morgagni (bent arrow). The contrast medium is almost completely expressed from the supraglottic space of the vestibule (open arrow). The subepiglottic space does not close and the contrast medium remains in it (thin arrow). The epiglottis (e) is not tilted down.

In 41 patients neither the subepiglottic nor the supraglottic space closed properly during the act of swallowing. Consequently, contrast medium entered the vestibule down to the level of the rima glottidis (Figs 3 and 4).

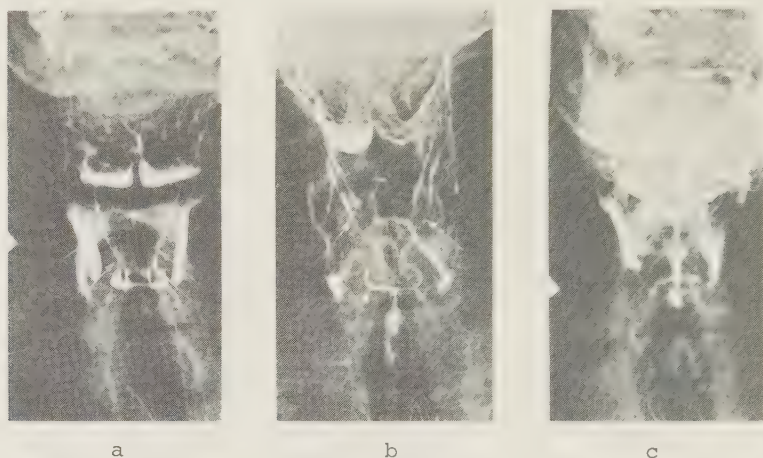


Fig. 4. Single film examination in different stages of vestibular closure. PA view. In a) the vestibule is open. In b) the rima glottidis (arrow) has closed and the ventricular folds and the sinus of Morgagni have closed. The retained contrast medium attains the form of a "tapered glass" with the foot thereof corresponding to the closed sinus of Morgagni. (ae aryepiglottic fold, sM sinus of Morgagni, ve ventricular fold, vo vocal fold).

In 1 of these 41 patients the subepiglottic and supraglottic spaces, i.e., the whole laryngeal vestibule, remained patent during the subsequent act of swallowing. In the remaining 40 patients the vestibule was closed but this closure was too late to prevent the entrance of contrast medium.

Apart from the delay in closure the vestibule behaved normally in 11 patients. In these the supraglottic space closed first, followed immediately by the subepiglottic space. In the remaining 29 patients the supraglottic space showed a delayed closure but the subepiglottic space did not close at all during the act of

swallowing.

Due to the delayed closure a minor portion of the contrast medium that had entered the supraglottic space was pressed through the closed rima glottidis into the trachea. The bulk of contrast medium was, however, ejected into the subepiglottic space and further into the mesopharynx.

In the 29 patients with non-closure of the subepiglottic space some contrast medium remained in this location throughout the act of swallowing. After deglutition this contrast medium was aspirated into the trachea on the first inspiration.

In addition a defective closure of the vestibule was encountered in 4 patients as contrast medium entered the vestibule - but not the trachea. However, the cineradiograms gave no information about the mechanisms involved in the misdirected swallowing of these patients.

Concomitant functional abnormalities were common (Table 1). Twenty-three patients had paresis of varying extension of the pharyngeal constrictor musculature. Abnormalities in the movements of the epiglottis were registered in 32 of the 58 patients with contrast medium passing only into the subepiglottic space, while 33 of 41 patients with contrast medium passing into the

Table I

	Category 1	Category 2
Epiglottic dysfunction	32	33
Pharyngeal constrictor paresis	11	12
Cricopharyngeal dysfunction	14	9
Zenker diverticulum	2	0
Webs	8	7
No concomitant abnormalities	19	5

Concomitant cineradiographic findings in 99 patients with defective closure of the laryngeal vestibule according to category (See text). Four patients with aspiration between swallowings are not included.

supraglottic space had epiglottic dysmotility either as an impaired second movement or as a total immobile epiglottis. Other concomitant abnormalities were dysfunction of the cricopharyngeal muscle, webs and Zenker diverticula.

DISCUSSION

From the results obtained in the present investigation it is clear that the defective closure of the laryngeal vestibule during swallowing can be distinguished into two principally different categories. The first category could be discerned as a delayed closure allowing entrance of contrast medium into the laryngeal vestibule. In many patients of this category the contrast medium reached as far down as to the level of the vocal folds. However, when the vestibule finally closed its content of contrast medium was expelled out into the mesopharynx and a small amount also into the trachea. The second category of faulty closing of the laryngeal vestibule, or more correctly its subepiglottic portion, could be discerned as an inability to close - the vestibule remained open during the whole time lapse of swallowing. Contrast medium entered the vestibule and remained there until it was either aspirated or expelled by vigorous coughing.

The first category of faulty vestibular closing may be explained by a defect in the subtle normal synchronization of the long row of events involved in the act of swallowing. Even a very short delay in the closure of the laryngeal vestibule will promptly result in an entrance of contrast medium into the vestibule. If the vestibule remains open when the pharyngeal pressure increases due to the contraction of the pharyngeal constrictors contrast medium will inevitably be pressed into the vestibule. In an earlier investigation it has been shown that the normal closure of the vestibule is effected by a compression from below (Ekberg, 1981). In the present investigation contrast medium reached the supraglottic level in 40 and the subepiglottic level in 55 patients before the vestibule started to close. This observation suggests that the degree of delay in vestibular closure will determine how far down into the vestibule the contrast medium will reach on swallowing.

The second category of insufficient vestibular closure - an inability to close - may be explained by a lesion that involves the neuromuscular supply of the vestibule. The precise pathogenetic mechanism is unknown but could be supposed to be more profound as, for instance, a temporary or permanent injury of the neuromuscular elements involved in the compression of the laryngeal vestibule.

An explanation of the observation about aspiration of contrast medium between two swallowings could be defective or absent sensitivity in the vestibule. The vestibule is under normal conditions very sensitive and richly innervated by sensory fibers via the internal branch of the superior laryngeal nerve (Pressman & Keleman 1955, Fink 1956). In the normal individual sensory stimulation promptly results in vestibular closure mediated via efferent impulses from the swallowing center in the reticular formation of the medulla oblongata. A proposed theory of an impaired sensitivity is supported by the fact that many of these patients are unaware of their misdirected swallowing. When part of the bolus has entered the vestibule this does not ultimately imply that bolus material also reaches the trachea, as aspiration further down into the airways often is prevented by a forceful expiration. This was frequently seen in patients with entrance of contrast medium beyond the subepiglottic space. Simultaneously with the opening of the rima glottidis and supraglottic space they tried to get rid of the contrast medium by means of forceful expiration or coughing before they started to inspire. This accessory mechanism seemed to be very effective in several patients.

In an earlier study of nondysphagial volunteers an incidence of epiglottic dysmotility of 5 percent was found (Ekberg & Nylander 1981 a). In 2 of these 7 individuals contrast medium reached into the laryngeal vestibule. This observation suggests that it is not only the tilting down of the epiglottis, over the laryngeal aperture, that protects the vestibule.

In another study of patients, suffering from dysphagia, defective tilting down of the epiglottis was a fairly common finding.

(Ekberg & Nylander 1981 b). However, 76 percent of these patients were found to have contrast medium entrance into the laryngeal vestibule on swallowing. These two observations suggest that even if the epiglottic movement is afflicted the vestibule can be compressed in individuals without dysphagia. However, if the individual is unable to close the vestibule by the thyroarytenoid and thyroepiglottic musculature, swallowing complaints will eventually occur.

Among individuals without dysphagia misdirected swallowing as defined above was seen in 8 of 150 examinations (Ekberg & Nylander, 1981 a). However, contrast medium among these individuals passed only into the subepiglottic space of the vestibule. This is in contrast to the present series where contrast medium frequently reached beyond the ventricular folds and even into the trachea.

Another striking difference between individuals with and without dysphagia was that in the former group the misdirected swallowing was more severe but also accompanied by other abnormalities in the act of swallowing. In the present series the dysphagial patients showed concomitant abnormalities in 79 patients (77 %).

The cineradiographic diagnosis of misdirected swallowing, i.e., contrast medium passing into the laryngeal vestibule with or without filling of the trachea by contrast medium, is preferably done on the lateral projection.

In the AP projection contrast medium in the vestibule is most readily disclosed when it has passed into the supraglottic space (Fig. 4). Here it accumulates in the sinus of Morgagni but also above the apposed ventricular folds where the contrast medium attains the form of a "tapered glass" with the foot thereof corresponding to the sinus of Morgagni.

Johnstone in 1942 reported on fluoroscopic observations revealing that the epiglottis tilts down during swallowing. However, the events of vestibular closure were incorrectly understood to start by closure of the superior laryngeal aperture. He also reported that radiograms showed an open rima glottidis when the vestibule was closed.

Ramsey et al. in 1955 quoted the above description of Johnstone and reported frequent filling of the vestibule by bolus material, but added that there was a reflex closure of the ventricular folds due to the filling. Neither Johnstone nor Ramsey and his co-workers correctly described that the rima glottidis closed simultaneously with the lifting of the larynx. This is actually an extremely invulnerable and symmetric reflex in the swallowing act. In a consecutive study of more than 600 patients performed by the author of this report, no patient has been found with an absence of this early closure of the rima glottidis. In patients with unilateral recurrent nerve palsy this closure is somewhat asymmetric but none the less effective (Ardran et al 1954, Pressman & Keleman 1955, Lund & Ardran 1964).

Ardran et al (1954), among others, have attributed the function of the vocal and ventricular folds to a valvular sphincteric function. In this way air should be prevented to flow from above between the vocal folds and from below through the ventricular folds. The results from the present study do not support this theory about the function of the folds. In the present series bolus material was seen to be hindered, frequently by the firm apposition of the ventricular folds, to enter the trachea. When this obstacle was overcome the vocal folds did not seem to be able to hinder the further passage of bolus material. Actually the valvular function at the level of the vocal and ventricular folds has been claimed to be a function of fonation, whereas a muscular sphincteric activity has been suggested to cause the closure at this level to prevent bolus material from passing into the trachea (Ardran & Kemp 1956).

Ardran and Kemp in 1967 stated that part of the bolus often passed into the vestibule down to the level of the vocal folds. This is an extremely rare phenomenon in nondysphagial subjects (Ekberg & Nylander 1981 a). Bachman (1959) in his report on swallowing mechanism claimed that the epiglottis was the only protection of the airways and that the true and false cords never acted as a competent safeguard against aspiration. He stated that "contrast, once reaching the vestibule is not hindered by the cords". However, his patients were obviously very disabled and

suffering from malignancies in the hypopharynx and also neurologic diseases.

The results of the present investigation indicate that misdirected swallowing is fairly common among patients with dysphagia compared to individuals without dysphagia. It is often accompanied by other abnormalities in the act of swallowing. When the radiologist is aware of the phenomenon it is easily recognized on the cinefilms. By diagnosing misdirected swallowing in patients with dysphagia the radiologist can disclose a probable explanation of the patients' complaints.

ABSTRACT

Two hundred and fifty patients with dysphagia was studied with cineradiography of the pharyngeal stage of deglutition. In 103 a defective closure of the laryngeal vestibule was disclosed. In 58 patients the closing of the supraglottic space, i.e., the inferior portion of the laryngeal vestibule was normal while the subepiglottic space, i.e., the superior portion of the laryngeal vestibule, was defective. In 41 patients neither the supraglottic nor the subepiglottic space closed properly during the act of deglutition. In 29 of these the contrast medium reached into the trachea. The defective closure of the laryngeal vestibule could be distinguished into two principally different categories. The first category could be discerned as a *delayed closure* of the vestibule allowing contrast medium to enter. This contrast medium was later expressed back into the pharynx when the vestibule was closed. The second category could be discerned as an *inability to close* - the vestibule remained open during the whole time laps of swallowing. The contrast medium remained in the vestibule until it was either aspirated or expelled by vigorous coughing.

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CERVICAL OESOPHAGEAL WEBS IN PATIENTS WITH DYSPHAGIA

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The clinical significance of webs located in the cervical portion of the esophagus has been the subject of much controversy. Some authors have claimed the insignificance of these webs (Miller and Lewis, 1963; Blendis et al., 1965; Seaman, 1967; Clements et al., 1974; Noshier et al., 1975). Still others have claimed that these webs can cause dysphagia (Mosher, 1927; Macmillan, 1935; Waldenström and Kjellberg, 1939; Waldmann and Turnbull, 1957). The aim of this investigation was to study the presence and appearance of webs among patients with dysphagia referred for x-ray examination of the pharynx and esophagus and to discuss their relation to concomitant functional abnormalities.

MATERIAL AND METHODS

The material consisted of 250 patients consecutively subjected to cineradiography of the pharyngoesophageal stage of deglutition due to dysphagia. It comprised 103 males and 147 females aged 18 to 95 years and with a mean age of 61 years. Prior to cineradiography the patients had been subjected to a thorough routine x-ray examination. This examination included fluoroscopy, plain films in different projections before and after barium swallowing as well as films taken during barium swallowing.

The cineradiograms were obtained with the aid of a Camématic GV 16 high-speed camera and a cine-pulse unit. The exposures were made at 75 - 80 kV and 125 mA. The exposure time was between 1 and 5 msec. Film series were obtained at a speed of 50 and 100 frames per second. Every cineradiographic examination comprised at least two AP and two lateral views. To obtain an optimal recording of the act of swallowing the patients were instructed to swallow a large mouthful of a barium contrast suspension (Barytgen^R 60 % w/w). After this initial barium swallowing the patients were asked to perform repeated secondary swallowings in order to prove their ability to clear the pharynx of contrast medium.

The obtained cineradiograms were analysed with a cine-film analector (Steenbeck ST 1100). The cinefilms were reviewed with

special references to the presence of cervical oesophageal webs. Attention was also paid to their eventual changing during the act of swallowing. Abnormalities in the act of swallowing, i.e., pharyngeal paresis of varying severity, misdirected swallowing, epiglottic dysfunction and incoordination of the cricopharyngeal muscle were also registered.

In order to estimate the diagnostic value of conventional films as compared to the cineradiograms the former were also reviewed with regard to the demonstration of cervical oesophageal webs.

RESULTS

Webs were detected on cineradiography in 38 patients, 8 males and 30 females. This corresponds to 15 percent of the total material and to 8 percent of the males and 20 percent of the females included in the material. The mean age of these patients was 68 years. When the conventional films taken prior to the cineradiograms, were scrutinised in a review webs were registered in 26 of the 38 patients (Fig. 1).



a



b

Fig. 1. a) PA projection, b) lateral projection. These conventional single film exposures demonstrate a web in the cervical portion of the oesophagus. The web involve the anterior and lateral aspects of the gullet.

The webs were restricted to the anterior aspect of the oesophageal wall in 22 patients. In 13 patients the webs involved the anterior and lateral aspects of the oesophageal wall (Fig. 1). In the remaining 3 patients the webs were seen to involve the anterior, lateral and posterior aspects of the oesophagus thereby encircling the gullet (Fig. 2). In 4 patients double webs were demonstrated (Fig. 3).

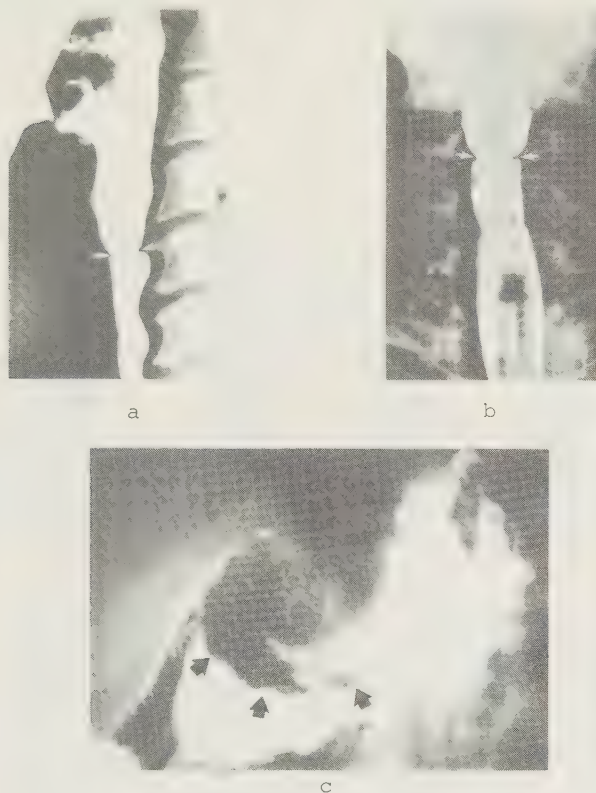
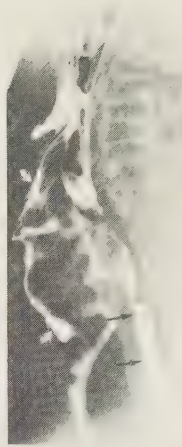


Fig. 2. a) PA projection and b) lateral projection of the pharynx and cervical oesophagus during swallowing. There is a web (arrow) that encircles the gullet. Near the cardia in the stomach there is a big carcinoma (c, thick arrows).



a



b

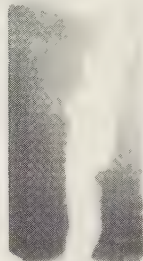
Fig. 3. a) PA projection, b) lateral projection. Conventional single film technique. There are two webs (arrows) in the cervical oesophagus seen both in the AP and the lateral projection. The oesophagus is not dilating properly between the two webs. Contrast medium has passed into the vestibule and trachea (bent arrow). The webs are located inferior to the cricopharyngeal muscle (open arrow).



a



b



c



d



e

Fig. 4. Sequence from a cineradiography in lateral projection. The cervical oesophageal web (arrow) is not visualized until the cervical oesophagus is well dilated by the bolus in d. The cricopharyngeal muscle is not relaxing properly during deglutition and is seen as an indentation (open arrow) throughout the sequence.

The appearance of webs in the cineradiograms changed during the act of swallowing. In 23 patients the webs were recognised as soon as the contrast medium reached the cervical oesophagus, whereafter they remained visible until the peristalsis emptied the oesophagus.

In the remaining 15 patients the webs appeared at first when the cervical oesophagus had been well filled with contrast medium for a while, i.e., they were formed during the course of the swallowing (Fig. 4).

In the secondary swallowings, when only a small amount of contrast medium passed the gullet, only 13 of the 38 webs were demonstrated by the cineradiography (Figs 5 and 6).

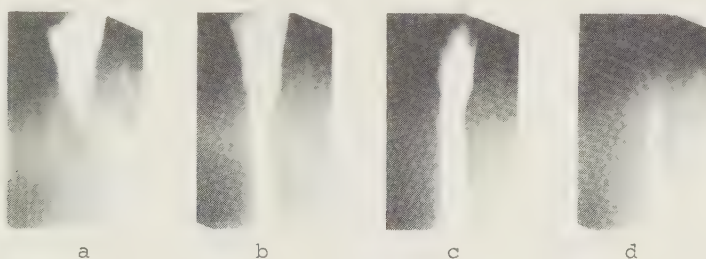


Fig. 5. Sequence from a cineradiography during swallowing of a moderate large bolus. No web is seen even when the oesophagus is well dilated by the bolus as in b and c. The cricopharyngeal muscle is visualised as a small and transient indentation in b (open arrow).

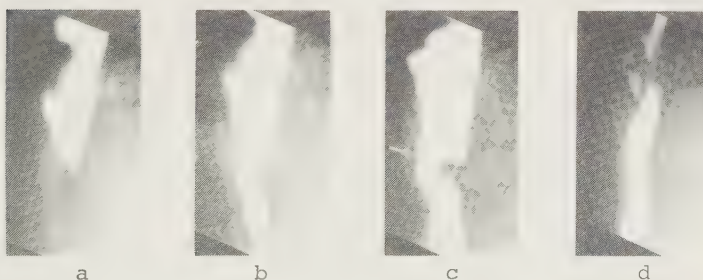


Fig. 6. Same patient as in Fig. 5. Sequence from a cineradiography during swallowing of a large bolus of contrast medium. A web (arrow) is visualised in the anterior wall of the gullet opposite the indentation due to the cricopharyngeal muscle (open arrow).

Concomitant functional abnormalities in the act of swallowing were seen in 25 patients (Table 1, Fig. 4 and 6). In 5 of the patients a malignant lesion was found as well. One patient had a squamous cell carcinoma of the right piriform fossa of the pharynx, another patient had a laryngeal carcinoma, two other patients had intrathoracic oesophageal squamous cell carcinomas, and the last patient had a carcinoma of the stomach close to the cardia (Fig. 2). One patient had a concomitant Zenker diverticulum.

Table 1. Concomitant cineradiographic findings in 38 patients with webs of the upper oesophagus.

Diagnosis	Number of patients	Percentage
Paresis of the pharyngeal constrictor musculature	3	8
Cricopharyngeal muscle dysfunction	18	47
Epiglottic dysfunction	8	21
Misdirected swallowing	15	40
No concomitant abnormalities	13	34

DISCUSSION

The first radiologic report on oesophageal webs was published by Mosher in 1927. He recognised that patients with oesophageal webs could suffer from dysphagia and that normal swallowing was restored in these patients if the webs were subjected to division. However, Clements et al. (1974) examined 100 unselected patients with a variety of gastrointestinal symptoms and found no evidence to support the opinion that webs could cause dysphagia.

Few reports have appeared in the literature about the incidence of webs in ordinary healthy people. In an intentional search for webs Waldenström and Kjellberg (1939) could only find a single web in 145 randomly selected asymptomatic individuals. Chisholm in 1971 found no webs in 98 healthy individuals and Elwood (1964) found webs in less than 1 percent in a population group of females. Ekberg and Nylander (1980a) performed a cineradiographic examination of 150 volunteers and found only a single web in one of them. However, in this context it is important to bear in mind that webs are illusive radiographic phenomena and very

often have a tendency to escape detection. Even if the examinations are performed in a skilled way with swallowing of a large bolus of contrast medium the webs may baffle detection. This was reflected in the present investigation where 15 of the 38 webs (39 %) were seen on cineradiography as transient phenomena during a short moment of the act of swallowing. Furthermore, the incidence of webs may vary between different populations in the same way as sideropenic webs are more common in northern European countries than in other parts of the world (Waldenström and Kjellberg, 1939).

The incidence of webs in patients suffering from dysphagia has been dealt with in a few reports in the pertinent literature. In 1935 Macmillan recounted an incidence of webs in patients with dysphagia of 7 percent. Elwood published an investigation in 1964 of 114 females and 21 males suffering from dysphagia and he found oesophageal webs in 16 females but none in the males. In a more recent study from 1979 of 191 patients with dysphagia Tada et al. found 33 patients with oesophageal webs. The material of the present investigation was obtained from a cineradiographic study of 250 patients with dysphagia in which 15 percent showed oesophageal webs (Ekberg and Nylander, 1980 b)

From the reports cited above it is clear that the incidence of webs in an ordinary population is around 1 per cent while the incidence of webs in patients with dysphagia is about 15 percent. This discrepancy in incidence suggests a clear connection between webs and dysphagia. However, the true and direct causal relationship between these two entities is still unclear.

As can be seen from the results of the present investigation webs were registered as the only radiographic finding in 13 patients while they were seen together with other deglutitional dysfunctions in the remaining 25 patients. In the former group of patients, where the webs were the only demonstrable aberration in the act of swallowing, one might feel tempted to accept the web as the real cause of the patients' dysphagia. In the latter group of patients, where the webs were found together with other swallowing aberrations, the pathophysiologic significance of the webs remains more obscure.

The oesophageal webs registered in this investigation varied in size: the majority of them were confined to the anterior aspect of the cervical oesophagus while a few were circular. As clinical problems were not involved in this investigation the results have so far not been examined for any correlation between the size of the webs and the severity of the patients' dysphagia. Yet it seems reasonable to assume that a large web will induce more pronounced dysphagial symptoms than a smaller one.

However, from a radiodiagnostic point of view another problem deserves much more interest. From the results it is clear that webs were seen on the routine radiographic examination in only 26 of the 38 patients included in the present cineradiographic investigation.

On cineradiography the webs often revealed themselves as temporary phenomena visible for only a fraction of the time during which the cervical oesophagus was filled with contrast medium (Fig. 3). This observation explains why the careful routine examination with films taken during barium swallowing in 12 patients failed to visualise webs that were easily detected by cineradiography.

Another observation is of the utmost radiologic interest in the diagnosis of webs. In many patients webs are formed in the oesophagus only if a fairly large contrast bolus is passing down the gullet (Fig. 6). A smaller contrast bolus fails to induce the formation of a web (Thomas, 1947; Elwood et al., 1964; Pitman and Fraser, 1965).

These two characteristics of the webs, their illusive and sudden appearance during an act of swallowing and their absence during another act of swallowing, have important radiologic implications. The presence of webs can never be excluded from even the best single "swallowing" film.

An exposure during swallowing of a large bolus is a prerequisite for the diagnosis of webs. However, such an exposure can be a rather difficult task even for an experienced radiologist and especially when the patients suffer from concomitant functional abnormalities in the act of swallowing.

Several patients in this investigation had webs with an oblique orientation in the AP projection. These webs were not visible in the lateral projections as they were not parallel to the x-ray beam (Fig. 7). This was especially the case when the webs were rather thin. However, even webs which were not apprehended as thin on the AP projection, were not disclosed on the lateral projection (Fig. 8). The results from the present investigation have made it clear that the diagnosis must be based on cineradiography. A correct diagnosis can also often be made by fluoroscopy. Fluoroscopy in this as well as in other respects requires experienced radiologists and cannot be reappraised after the patient has left the department. This is in contrast to cineradiography which can be performed by an unexperienced radiologist and later analysed repeatedly. In this way a cineradiographic examination is more convenient for both the patient and the radiologist and gives more reliable diagnostic information compared to conventional single-films.

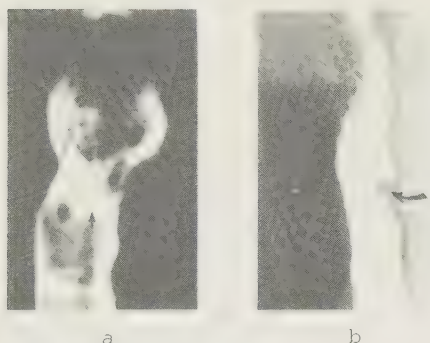
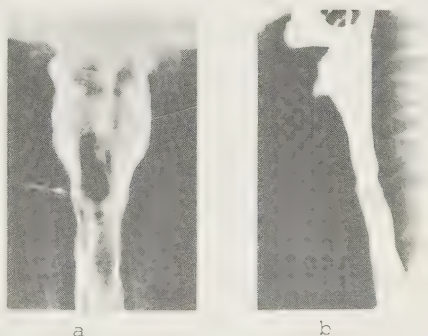


Fig. 7. a) PA projection
b) lateral projection of the pharynx. The thin and oblique web (arrow) is only visualised in the PA projection. There is an indentation (bent arrow) due to the cricopharyngeal muscle.

Fig. 8. a) PA projection
b) lateral projection. In the PA projection there is seen a web (arrow) in the cervical oesophagus. This is not seen in the lateral projection.



Five patients in the present series had concomitant malignant lesions. This high incidence of malignant lesions among patients with cervical oesophageal webs has been reported earlier (Waldenström and Kjellberg, 1939; Lindvall, 1953; Welin, 1953). When a malignant lesion occurs in the hypopharynx or oesophagus in a patient with a web it is not located at the site of the web. This means that the web is not per se precancerous but may indicate the presence of a concomitant malignancy.

The results from the present study show that cervical oesophageal webs are common among patients with dysphagia. They may occur together with a malignancy in adjacent organs, i.e., the larynx, pharynx, oesophagus and stomach, are frequently concomitant with functional aberrations in the act of swallowing and are twice as common among women compared to men.

Summary

A series of 250 dysphagial patients examined with cineradiography and conventional single-film technique revealed oesophageal webs in 38 and 26 patient, respectively. In 4 patients there were two webs. There were 8 males and 30 females which corresponds to an incidence of 8 and 20 percent, respectively (mean 15 %), in patients referred for x-ray examination of the pharynx or oesophagus due to dysphagia. Concomitant functional aberrations in the act of swallowing were disclosed in 25 patients, i.e., pharyngeal constrictor muscle paresis of varying extension, cricopharyngeal incoordination, misdirected swallowing, epiglottic dysfunction and Zenker diverticulum. In 5 patients there was a malignant lesion as well, i.e., in the larynx, oesophagus, pharynx or stomach. With the aid of cineradiography it is possible to disclose the presence of webs in a significantly higher proportion of dysphagial patients compared with conventional single-film technique. With cineradiography it is also possible to demonstrate concomitant functional abnormalities which are frequently present in these patient.

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